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173

Kari Rantakokko and Bertel Vehviläinen (ed.)

Nordic Workshop on HBV and Similar Runoff Models

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PREFACE

Summary of the content of the workshop

HBV -based hydrological models are used in more than 40 countries all over the world, especially in Nordic countries. The use and development of the models have been carried out partly individually by several institutions and a variety of applications and versions are in use. Also the Nordic countries have their own development projects, although cooperation in some respect have been carried out. Despite of that separate model versions are in use in Nordic countries. Several organisations and groups are working in order to improve model processes and accuracy for forecasting and simulation purposes. It would certainly be a benefit for different researchers and scientists to be more in contact with other HBV-related model developers in order to promote cooperation and exchange of information. During the summer and autumn 1998 an idea rose out to arrange a meeting between persons involved in hydrological models in Nordic countries. The decision to arrange a meeting was made together with representatives of the Finnish Environment Institute and Kemijoki Ltd., a major hydro power company in Finland.

The actual workshop, the first one of its kind, was arranged on 19 - 20 November 1998 in the Finnish Environment Institute. There were altogether 23 participators from Norway, Sweden and Finland. The list of participators is enclosed on page 6. The content of the workshop was divided into four separate sessions, namely:

- Session I: The present stage of HBV-models (chairman Pertti Seuna)
- Session II: Experiences and development needs by the users of HBV-model (chairman Dan Lundquist)
- Session III: The ongoing development related to the models (chairman John Forsius)
- Session IV: New ideas and future cooperation (chairman Sten Bergström)

The workshop was opened by Dr. Pertti Seuna from the Finnish Environment Institute. Totally 13 presentations were held by the participants covering the issues important for model users, developers and those having responsibility of lake regulations and hydro power production. Contributions of major part of all presentations (10) are collected together to be presented in this publication. The contribution prepared by Jukka Hassinen (Regional Environment Centre of Northern Savo) could unfortunately not be presented during the workshop but it is published along with other papers.

In the end of the first day a get-together event was arranged in the Finnish Environment Institute to give a possibility for participants to have informal discussions of interesting issues. The event was hosted by Mr. Hannu Puranen from the Kemijoki Ltd.

The first version of the conceptual HBV model has been made in 1972 at the water balance section of the hydrological bureau of SMHI (HBV = Hydrologiska Byråns Vattenbalans-avdelning). The aim for further development was to have a version for operational purposes. First operational test forecasts were made in 1975. The latest versions are fully distributed. The history of HBV is described in more detail in the contribution made by Sten Bergström.

Possibilities for future cooperation

Aims

The overall goal of the workshop was to look ahead to find ways for continuing and expanding the co-operation in the area of HBV-related rainfall-runoff models used for research and operative purposes. On-going projects and nationally starting projects are giving a good base for future cooperation and possible joint projects. From this point of view it can be named two important on-going projects within there are already co-operation between some participants and can be a base for future cooperation.

The first one is **BALTEX**-project which aims to study the water and energy balance of the Baltic Sea basin area. The large coverage of operational HBV-forecasting models in the Baltic give Nordic hydrologists a strong position to take part in the development work by using real time model results for connecting hydrological and meteorological models. Especially snow cover and soil moisture simulations are ready to be used to verify same elements in meteorological models.

The second project is climate change scenario simulations made in **SWECLIM**-project in Rossby Centre. The temperature and precipitation scenario simulations made by HIRLAM-model cover all Nordic countries except Iceland and the results are available for researchers provided by national meteorological institutes.

On national level in Finland there are two relevant projects. The use of **weather radar** precipitation data in hydrological forecasting is developed for the real-time use in the Kyrönjoki river basin. The radar data will be tested for forecasting purposes during summer 2000. The other project is an application concerning micro-wave **satellite** radars used for **snow-mapping.** Snow radar applications on visible light with NOAA-satellite data have been used in Sweden and especially in Norway with some success. The simulated snow cover area in hydrological forecasting models can be updated through this data.

Hydrological process orientated research
Hydrological models gives a wide background for hydrological process orientated research. The process studies are very suitable to form joint projects, because new sub-process models are quite easy to be implemented in to forecasting systems in each country. The possible study areas are: evaporation, snow (distribution, accumulation, melt), soil frost, soil moisture, ground water, physical hydrological models (Ecomag in Norway). The results of internal validation of HBV-models are part of sub-process studies done in many Nordic countries and the achieved results may be good to put together.

Uncertainty in forecasts
One very important topic in forecasting is uncertainty in hydrological forecasts; how to quantify and express it to end-users. To introduce the uncertainty in meteorological forecasts into hydrological forecasts is not always clear. The end-users of hydrological forecasts asks always better information of uncertainty.

Areal precipitation
Areal precipitation input to hydrological models is considered to be one important area to improve the accuracy of simulations of hydrological models. SMHI presented the optimal interpolation method used in HBV-96 model version.

River systems with reservoirs
Markus Huttunen from Finland (FEI) presented neural network application for optimizing lake regulations in large watersheds consisting of 10-20 regulated lakes. The system is capable to decide optimum regulation practises in real-time forecasting situation according to the rules given to the model. Neural network model is "calibrated" by using long time series. After this the model is ready for real-time operation. This model is useful for different forecasting situations, when water levels and releases of lakes should be as realistic as possible. This kind of system is needed in the Vuoksi basin consisting up to 20 regulated lakes and it can also be an application in other basins too.

Conclusions
During the final session there was a discussion of the ways how to promote cooperation and further research in the future. The major possibilities which arose are:

- HBV-meetings arranged regularly
- EU/Nordic -based co-project
- Web -home pages for HBV -related research, development and applications
- personal contacts (more detailed information)

HBV -meetings can be arranged individually or for example simultaneously with other project meetings or as a parallel session in Nordic Hydrological Conferences held every second year (next one at the year 2000). Potential themes for workshops are for example parametrisation of snow and vegetation, data assimilation, informal model intercomparison, model updating/error correction and water quality simulations.

Finally, we want to thank all those persons, who have contributed in the realization and helped in the arrangements of this workshop. Special thanks are directed to Kemijoki Ltd. and Fortum Plc. of their support.

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Kari Rantakokko
Finnish Environment Institute
Hydrology and Water Management Division

Bertel Vehviläinen
Finnish Environment Institute
Hydrology and Water Management Division

List of the participants

	Email-address
Sweden	
Sten Bergström, Swedish Meteorological and Hydrological Institute	sten.bergstrom@smhi.se
Barbro Johansson, Swedish Meteorological and Hydrological Institute	barbro.johansson@smhi.se
Göran Lindström, Swedish Meteorological and Hydrological Institute	goran.lindstrom@smhi.se
Birgitta Adell, Gullspångs Kraft	biad@gka.se
Norway	
Elin Langsholt, Norwegian Water Resources and Energy Directorate	egl@nve.no
Hans Christian Udnaes, Norwegian Water Resources and Energy Directorate	hcu@nve.no
Kolbjorn Engeland, University of Oslo	kolbjorn.engeland@geofysikk.uio.no
Trond Rinde, SINTEF Construction and Environment	trond.rinde@civil.sintef.no
Dan Lundqvist, Glommen's & Laagen's Water Management Association (GLB)	danlund@online.no
Nils Roar Saelthun, Norwegian Institute for Water Research	n.r.salthun@geofysikk.uio.no
Finland	
John Forsius, FORTUM Plc.	john.forsius@fortum.com
Tuomo Sinisalmi, FORTUM Plc.	tuomo.sinisalmi@fortum.com
Urpo Kakko, FORTUM Plc.	urpo.kakko@fortum.com
Hannu Puranen, Kemijoki Ltd.	hannu.puranen@kemijoki.fi
Juho Päiväniemi, Kemijoki Ltd.	juho.paivaniemi@kemijoki.fi
Jukka Höytämö, Regional Environment Center of Northern Karelia	jukka.hoytamo@vyh.fi
Pertti Seuna, Finnish Environment Institute	pertti.seuna@vyh.fi
Bertel Vehviläinen, Finnish Environment Institute	bertel.vehvilainen@vyh.fi
Markus Huttunen, Finnish Environment Institute	markus.huttunen@vyh.fi
Kari Rantakokko, Finnish Environment Institute	kari.rantakokko@vyh.fi
Markku Puupponen, Finnish Environment Institute	markku.puupponen@vyh.fi
Risto Lemmelä, Helsinki University of Tehcnology	rlemmela@ahti.hut.fi

Contents

1. THE HBV STORY IN SWEDEN

Sten Bergström
Swedish Meteorological and Hydrological Institute
Norrköping, Sweden

Introduction

The story of the Swedish HBV model dates back to 1972 when the first successful run was made at the water balance section of the hydrological bureau of SMHI (Hydrologiska Byråns Vattenbalansavdelning, HBV; Bergström and Forsman, 1973). The aim was to come up with a hydrological model for operational use according to the following main principles (Bergström, 1991):

- The model must be based on a sound scientific foundation
- It must be possible to meet its data demands in most areas
- Its complexity must be justified by its performance
- It must be properly validated
- The user must be able to understand the model

In 1975 the model was first tested for operational forecasts in the upper parts of River Ångermanälven. The same year the model was introduced in Norway. Since then the number of institutions involved in the development has increased and the scope of applications has widened. Today there exist a variety of model versions, with origins from different institutions, and applications have been made in more than 40 countries.

One important factor for the widespread use of the HBV model in Sweden was the development of personal computers. A strategic decision was taken to develop the Windows based Integrated Hydrological Modelling System, IHMS. This proved to be the right way and paved the way for more de-centralised use of the model. It became more and more evident that a model, no matter how good it is, is of little value unless it comes with a user-friendly interface. The ease of handling has improved further by the introduction of more reliable routines for automatic model calibration (Lindström, 1997).

Swedish HBV Models

The HBV model started as a very simple lumped hydrological model and has gradually been developed into a distributed model. With the latest release, HBV-96 (Lindström et al., 1997), full distribution into subbasins and statistical distribution of some properties within these have become the basic principle. It is therefore fair to say that the HBV model now is a distributed hydrological model.

The HBV-96 has also a new response function, which requires four instead of five parameters, and thus is less susceptible to overparameterisation (too many free coefficients to calibrate). This new routine gives a slightly better representation of peak flows.

Proper soil moisture accounting is a key to successful hydrological modelling. The HBV model was one of the firsts, if not the first, model to adopt a variability parameter in the soil moisture procedure. This was introduced in 1972 and there has not been any reason to change the concept since then. The technique has proved to be very efficient and has been copied into other hydrological models as well. Very recently it was also tested in the response function of the HBV model to cope with the problems with variable dynamics of winter and summer peaks.

In addition to different models, mainly developed for runoff modelling, a new branch of models appeared for water quality related research. In an attempt to modernise the name the PULSE model was introduced. It was, however, soon realised that this new name of a model, which in practise was a modified HBV, model created a lot of confusion. The name PULSE has therefore been abandoned in favour for the more established HBV.

Scope of Applications

Hydrological Forecasting

The HBV model was initially intended for runoff simulation and hydrological forecasting. The number of applications grew to cover most rivers in Sweden where flood forecasting and reservoir operation is an issue. Applications abroad became more frequent and a joint modelling project was carried out with countries in Central America among others (Häggström et al., 1990). Of great significance for the confidence in the HBV model was also the intercomparison of operational models for snowmelt runoff organised by WMO in the 1980s (WMO, 1986).

Today hydrological forecasting is probably still the most frequent type of application of the HBV model, both in Sweden and elsewhere. Research is still going on, in particular as concerns supplementary input from remote sensing and meteorological analysis techniques. More handy systems for real-time updating are also being developed.

Free Model Simulations

The traditional way of using a conceptual hydrological model is by first calibrating it, to find optimum values of its empirical parameters (coefficients). It was long felt that the need for calibration was an insurmountable limitation of the HBV model. Along with increasing experience, however, it was shown that the span of optimum values was not very dramatic. The idea of using the model without calibration (free simulations) grew from a need to relate long records of hydrochemistry to hydrological conditions in rivers, where runoff records simply do not exist. From a scientific point of view this application is still questioned, but not from a practical point of view. Free simulations are definitely better than not having any information at all.

The prerequisite for free model simulations is that that there is little variation in model coefficient or that we can find relationships between these and catchment characteristics. This was studied in the early 1990s with some success (Johansson, 1994). Today the HBV model is run with generalised coefficients in some 400 basins in Sweden.

Water Balance Mapping

Following surprising floods in southern Sweden in 1980 a synoptic hydrological map was developed as an automatic tool to give hydrologists a quick view of the hydrological situation (Bergström and Sundqvist, 1983). The mapping technique, based on hydrological modelling, developed further and it was decided to use it for the production of the volume of the National Atlas of Sweden dealing with climate, lakes and rivers. A gridded HBV model was developed with a resolution of 25 by 25 km and used for the production of the runoff map of Sweden launched in 1995 (SNA, 1995). Again the principle of generalised model coefficients was used.

At present a modified HBV soil model is used for real time mapping and assessment of the risks for forest fires in Sweden (Gardelin, 1996).

Design Floods

Forecasting was the main task of the HBV model until the early 1980s. This was when we realised that we have a spillway design problem connected to the reservoirs of the Swedish hydropower system. New guidelines for hydrological design were developed and adopted in 1990, and all of a sudden there was a new role for the HBV model (Bergström et al., 1992; Lindström and Harlin, 1992). A hydrological model of this type is a powerful tool for computation of hypothetical design floods, which have not yet occurred, but can not be ruled out. A model for design flood simulation in a multiple-reservoir river system was developed. It is based on an iterative approach, where the most critical timing of flood generation processes is sought. This method is a present being implemented in connection to a hydrological re-assessment of all major Swedish dams (Norstedt et al., 1992).

Analysis of Land Use Impacts

The events in the 1980s triggered a debate on the impact of land use on flood risks. In particular clearcutting and forest drainage were suggested as aggravating floods. The HBV model, although not being fully physically based, was used as an analysis tool. It could, at least, give some crude estimates of potential consequences. It was concluded that the main problem was underestimation of natural variabilities as concerns extremes and disharmony in infrastructure development, while land use probably has more limited impacts (Brandt et al., 1988; Johansson and Seuna, 1994).

Groundwater and Soil Moisture

It was with some hesitation that we decided to try the HBV model for simulations of groundwater recharge. Nevertheless it could be shown that the storages of the response function of the HBV model could be used to describe at least the response of the unconfined aquifers of a catchment (Bergström and Sandberg, 1983). The model could not be used for the three dimensional flow of groundwater, but gave realistic recharge values.

The application to ground water forced us to some re-interpretation of the model structure and gave very useful insights into the possibilities and limitations of the model. It became the starting point for further water quality oriented work. The same can be said about attempts to simulate the concentrations of the stable natural isotope oxygen-18. It seemed that we had reached the limit of the simple structure, when we wanted to model the fate of one molecule of water on its way from the top of the soil to the watercourse (Lindström and Rodhe, 1986). The introduction of a fair amount of extra water in the soil and ground helped overcome the problem. Proper retention times in various geochemical environments are of importance in detailed hydrochemical modelling. The modified model was thus used to provide input to geochemical models for studies of risks for groundwater acidification.

Parallel to the detailed studies of retention times more direct soil moisture simulations with the HBV model, or modifications thereof, were carried out by Andersson (1989A; 1989B)

Water Quality

It has become more and more evident that proper hydrological modelling is a prerequisite for water quality modelling. The latter type of modelling is also more difficult. Several attempts to expand the HBV model into water quality have been made over the years. The conclusion is that it can be made if the level of ambition is realistic. This means that simulations of climate induced variabilities, based on stationary conditions, are possible while it remains to be seen whether models can be developed for changing environmental pressures.

The climate induced variability of pH and alkalinity in forested rivers was modelled by the PULSE model in the 1980s (Bergström et al., 1985). Later focus has shifted to eutrophication and in the late 1990s the transport of nitrogen to the coastal waters from southern Sweden was modelled by some 4000 HBV models equipped with subroutines for nitrogen retention (HBV-N; Arheimer and Brandt, 1998).

Climate Change Studies

Climate change due to human activities is one of the greatest scientific issues today. In spite of all uncertainties in regional climate outlooks, hydrological models are in use for water resources impact studies since the early 1990s. The HBV model is no exception (Vehvilainen and Lohvansuu, 1991). A Nordic study on climate change and hydropower production was finalised in 1998 (Saelthun et al., 1998). The work was based on regional climate scenarios and a modified HBV model. This work will continue within the Swedish programme for regional climate modelling, SWECLIM, where the Rossby Centre is providing climate scenarios.

Proper modelling of evapotranspiration seems to be a general problem when using hydrological models for water resources scenarios. The issue is how the evapotranspiration routine shall be modified to realistically describe climate change conditions.

The climate issue has brought meteorologists and hydrologists closer together. A need for harmonisation of soil parameterisations has been identified as the energy and the water cycle will have to be solved simultaneously in the models. This debate will have strong impacts on future model development in meteorology as well as in hydrology. Of special interest is the scale problem. To bridge the scale gap between hydrological models and climate models the HBV model was applied to the land area of the entire catchment of the Baltic Sea (Graham, 1999). Regarded as a river basin it is the largest in Europe, some 1 700 000 km^2 excluding the Baltic Sea itself. The model has then been used for a review of the process descriptions in respective models. Already now some critical needs for model improvements have been identified (Graham et al., 1998).

The Future

It is realistic to believe that the HBV model will remain a standard hydrological tool for many years to come. There is a great need for simple techniques that link meteorology to hydrology and where human impacts can be distinguished from the effects of natural climate variability. Of special promise is the joint interest among climate modellers and hydrologists in better surface parameterisations (snow, soil and evapotranspiration) which is a key subject for the BALTEX research programme and other continental scale experiments within GEWEX. It seems that the scale problem, at least partly, can be overcome by a conceptual model of this type (Bergström and Graham, 1999)

Although the hydrological modelling technique is now well established in the Nordic countries, there is still some room for further development of the hydrological models. This is particularly the case for peak flow simulations. The greatest potential, however, lies in better representation of the input to the models. Work is in progress on introducing remote sensing as well as more advanced meteorological interpolation techniques to achieve this.

The hydrological water quality models in use are still relatively pre-mature. Better models, that link atmospheric deposition and hydrology to effects on the ecosystem, are urgently needed. For regional problems, like the eutrophication of the Baltic Sea, these models have to address the continental scale.

One common problem in all modelling is the risk for compensating errors. Models might perform well for the wrong reason. This might block further development, as improvement in one process description falsely may be interpreted as a failure, if we do not get rid of a compensating error simultaneously. To cope with this problem we have to pay more attention to internal process validation in our models in the future

The use of hydrological models requires up-to-date user-friendly computer systems and effective data collection and processing procedures. This has to be worked out in close co-operation with day-to-day users of the systems. For the continental scale applications proper data exchange between nations has to be secured.

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2. HYDROLOGICAL FORECASTING AND REAL TIME MONITORING: THE WATERSHED SIMULATION AND FORECASTING SYSTEM (WSFS)

Bertel Vehviläinen
Finnish Environment Institute
P.O. Box 140, SF-00241 Helsinki

Abstract

A real-time monitoring and forecasting system based on hydrological watershed models is widely used in Finland for forecasting and real-time monitoring. The main operating part of the watershed simulation and forecasting system (WSFS) consists of 20 watershed models, which simulate the hydrological cycle using standard meteorological data. The watershed models cover 286 000 km^2 or 86% of the area of Finland. Forecasts are made for 277 water level and discharge observation points in lakes and rivers. The number of annual water level and discharge forecasts is over 30 000. Forecasts are usually made twice a week or daily during flood periods. A map-based user-interface and Internet pages with forecasts and real time hydrological maps are included in the WSFS.

Introduction

The operation of a watershed model consist of meteorological and hydrological data collection, basic simulation run, updating of model accuracy according to observations, model runs with different regulation rules for regulated lakes, forecasting run with weather forecast and weather statistics and the delivery of forecast to Regional Environment Centres, other users and Internet. Owing to the large number of forecasts done, the entire operating system has been developed into a fully automatic form. Forecast and simulation results are presented as graphs of discharges, water levels, water equivalent of snow, areal precipitation, soil evaporation, lake evaporation and daily temperatures. The forecast covers up to six months at most if needed.

The developed map-based user-interface makes it possible to examine on a map hydrological variables simulated by watershed models in altogether 3500 different sub-basins or 50% of Finland. At the user-interface it is possible to choose the watershed in interest. Within this watershed, one can move between first, second and third level of watershed sub-divisions. In each level all the simulated daily data are available. The map-based user interface contains information from snow, soil moisture, discharge, runoff, temporary, subsurface and groundwater storages, lake levels and inflows into lakes. The map-based user-interface is mostly used to monitor and collect areal hydrological information. This interface provides large amount of otherwise hardly available data in real time.

Part of the forecasting results can be reached through Internet. Forecast to Internet are delivered for 50 lakes and rivers. Hydrological water balance maps are presented also. Available are maps of water level, water equivalent of snow, daily snowmelt, runoff, soil moisture deficit and soil evaporation over Finland. The address to the home page of WSFS is

http://www.vyh.fi/tila/vesi/ennuste/index.html. The forecast for different lakes and rivers can be chosen by clicking the watershed in interest on the map of Finland.

General Description of the System

The main operating part of the watershed simulation and forecasting system (WSFS) consists of 21 watershed models (Table 2 and Fig. 1) which simulate the hydrological cycle using standard meteorological data. The other independent systems to which the WSFS is connected are hydrological data register (HYTREK), operative watershed management system (VKTJ), automatic real-time water level and discharge station net (PROCOL), synoptic weather stations of Finnish Meteorological Institute (FMI), weather forecasts from European Centre of Medium-Range Weather Forecasts (ECMWF) via the FMI.

The WSFS reads watershed data from the registers, runs forecasts and distributes results to the Regional Environment Centres and to the Internet. The different stages in watershed forecasting are:

I. Meteorological data transfer in real-time from the FMI.
II. Automatic collection of hydrological data from registers: HYTREK, VKTJ, and PROCOL.
III. Automatic watershed model updating according to water level and discharge observations in real-time.
IV. Forecast runs by watershed models.
V. Distribution of forecasts through the data net to the Regional Environment Centres and other users.
VI. Data updating for the map-based user interface of WSFS.
VII. Forecast and hydrological map updating to the Internet: http://www.vyh.fi/tila/vesi/ennuste/index.html.

The Data Sources of the System

The FMI sends by E-mail daily precipitation from 170 stations and temperature from 48 synoptic stations. A 10-day precipitation and temperature forecast from the ECMWF is delivered to WSFS via FMI.

The watershed models need also potential evaporation observations, for which Class-A pan values are used. Class-A pan stations (20) report with a 1-month delay, leading to the use of monthly mean values in real time or potential evaporation is simulated by a temperature dependent model.

Hydrological data, water levels and discharges, are gathered from different sources. For real-time forecasting the most important source is the PROCOL system (Puupponen 1988), which delivers water level and discharge data in real-time to the registers and models. The other source is the VKTJ in which water level and discharge data are stored manually or other organizations send it by E-mail. These real-time hydrological data are crucial for accurate forecasting system; the watershed models are updated according to this information.

Most of the hydrological data can be obtained with a 1-2-month delay from HYTREK. These data can be used to update more sub-basins, which increases the accuracy of the watershed models.

Snow line measurements are available from HYTREK with some delay and are used to check the accuracy of areal snow simulations of the watershed models (Table 1).

Table 1. Meteorological and hydrological data used in the watershed models

Observation	Institute	Number	Delivery
Precipitation			
-Synoptic stations	FMI	48	daily
-Precipitation stations	FMI	170	daily
Temperature			
-Synoptic stations	FMI	48	daily
Potential evaporation			
-Class-A pan	FEI	22	monthly
Water level			
-Hytrek	FEI	272	monthly
-Procol	FEI	50	daily
-VKTJ	FEI	51	daily
-VKTJ	FEI	15	weekly/monthly
Discharge			
-Hytrek	FEI	175	monthly
-PROCOL	FEI	50	daily
-VKTJ	FEI	36	daily
-VKTJ	FEI	11	weekly/monthly
Snow line			
-Hytrek	FEI	117	biweekly

Watershed Model Implementation

The basic component of a watershed model is a conceptual hydrological runoff model (Bergström 1976, Vehviläinen 1994) which simulates runoff using precipitation, potential evaporation, and temperature as input. The main parts of the hydrological model are precipitation, snow, soil moisture, subsurface, and ground water models. This hydrological model is calibrated more or less specifically for all the sub-basins in the watershed depending on the available data.

Watershed model implementation begins by dividing the watershed into sub-basins according to the classification of Finnish river basins presented by Ekholm (1993). The aim is to divide the watershed into small homogeneous sub-basins according to elevation, land use, snow distribution and lakes. The number of sub-basins within a watershed model is typically 30 - 100; for each the hydrological runoff model is calibrated. The area of a sub-basin ranges from 50 km^2 to 500 km^2. Regulated, large unregulated, observed, and otherwise important lakes are described by lake model. This allows the correct simulation of water levels and outflow in a lake and improves the simulation of areal runoff and discharges. Finally the basic hydrological runoff and lake models are connected with river models to form the watershed model.

The optimization criteria in the calibration are the sum of the square of the difference between the observed and simulated water equivalents of snow, discharge, and water level. All available observations are used in the calibration and thus up to 100 different calibration criteria can be available in a watershed model calibration.

Table 2. Watershed models in the simulation and forecasting system (WSFS) of the FEI. Presented are watershed id. number, name, area of model, number of calibrated sub-basins, discharge (Q-points) and water level simulation points (W-points) with observations and forecast intervals during normal and flood situation.

Watershed		Area km^2	Sub-basins	Q-points	W-points	Forecast intervals normal/flood situat. days
34	Säkylän Pyhäjärvi	635	40	3	4	3/1
36	Karvianjoki	3 110	20	6	8	3/1
42	Kyrönjoki	4 805	30	5	5	3/1
44	Lapuanjoki	3 690	40	8	10	3/1
47	Ähtävänjoki	1 740	30	3	3	7/1-3
49	Perhonjoki	2 335	5	5	3	-/1-3
54	Pyhäjärvi Pyhäjoki	673	10	1	1	7/3
57	Siikajoki	3 470	5	5	4	7/1
63	Kuivajoki	1 270	5	2	1	7/1-5
64	Simojoki	3 125	10	2	1	3/1
65	Kemijoki	47 615	50	15	5	3/1
67	Tornionjoki	33 555	37	11	6	7/1
71	Paatsjoki	14 575	40	7	2	3/1
59	Oulujoki	19 890	40	15	11	7/1-3
4	Vuoksi	61 265	70	35	30	2/3
14	Kymijoki	36 535	305	49	65	2/3
35	Kokemäenjoki	26 925	207	33	76	3/1
53	Kalajoki	3 005	79	15	10	3/1
61	Iijoki	14 315	79	20	20	3/1
21	Vantaa	1680	100	10	10	3/1
1	Jänisjoki	1883	40	2	2	3/1
Sum		286 096	1192	252	277	-

Operational Use of Watershed Models

The WSFS has an automatic model updating system developed in the FEI. This updating system guarantees that the watershed models are in the best possible state before forecast evaluated according to observations and also makes the updating possible: a task impossible to do manually due to the large amount of simulated observation points (277) and sub-basins (1192). Model updating is done against the water level and discharge data gathered from different registers. When new watershed data become available the updating procedure corrects the model simulation by changing the areal values of temperature, precipitation and potential evaporation so that the observed and simulated discharges, water levels and water equivalent of snow are equal.

Short-term forecasts are the relevant forecasts for watersheds with short response times and low lake percentages, where the time between snowmelt or rainfall event and flood is only a few days. These watersheds with short response time need real-time data from discharges and water levels and continuous updating to maintain the quality of simulations and forecasts. Forecasts must be made daily in flood periods. The 10-days temperature and precipitation forecast from

ECMWF is the main meteorological input for forecasting period. After that statistical values are used.

In long-term forecasting the statistical precipitation, temperature and potential evaporation data are more important than the 10-days weather forecast. The hydrological forecast is based on mean (50%), 5 or 10 % and 90 or 95 % precipitation sums for 1, 2, 3, and 6 months. Especially at the beginning of winter, long-term forecasts are sensitive to temperature; thus the 25, 50 and 75% probability values for temperature are used for the first month.

Usually forecasts are made once or twice a week, even for the largest watersheds with long response times. This is done partly to test the entire system from the data collection to the delivery of results for possible problems to correct them in time before the forecasts are mostly needed. For watersheds with short response times twice a week is too seldom a forecasting frequency during floods; thus forecasting runs are started by the system whenever rainfall, discharge or water level exceeds a given limit.

Watershed forecasts are used for the supervision of water levels, discharges, snow, soil moisture and runoff formation. In flood situations watershed models are used to plan the regulation of lakes and reservoirs to minimize the flood damages. The forecast of possible overtopping of river embankments helps the Regional Environment Centres to take necessary precautions in advance. The ability of watershed models to simulate water equivalents of snow is valuable when estimating flood potentials during snowmelt periods in real-time.

In more slowly responding watersheds with abundant lakes the forecasts are used for long-term planning of regulation. It takes 1 - 2 months from a flood peak to flow through the Vuoksi watershed via long lake courses. The precipitation between forecast day and future flood peak strongly affects the final results. Statistical precipitation, temperature and potential evaporation series must be used to provide the needed information.

The computer network in the FEI and especially the Internet gives excellent possibilities for delivery of watershed forecasts to the Regional Environment Centres and other users. Regional Environment Centres could then inform and supervise all local authorities and organisations needing the information in their work. In the case of flood danger the Regional Environment Centres and FEI inform the press, radio and television.

Map-based User Interface

A map-based user-interface developed for WSFS makes it possible to examine on a map the hydrological variables simulated by watershed models in different sub-basins 3500 altogether covering 50% of Finland. At the start-window of map-based user interface the watershed of interest is chosen. From the chosen watershed with the first level sub-basin division one can go to second (Fig 2) and even to third level sub-division. In each level all the data, are available: snow water equivalent, soil moisture, discharges, storages, lake level, inflow and groundwater storage.

From an 'output'-icon it is possible to store any simulated daily data into a file for further use. This possibility is intended especially for users who need discharge and runoff data for areas and rivers with no observations. The map-based user interface is a source of simulated discharge values for 3500 sub-basins over 160 000 km^2 of Finland for use with water quality observations, planning, etc., when it is impossible or too expensive to make direct observations. The time range for the simulated data is 2 months backwards from the day of model run. Longer series are also available by request. The simulated data are used also for real time watershed -

monitoring and water resources management. The quality of simulated data is maintained by continuous updating of the watershed models against the observed water level and discharge values.

The map-based user interface is mostly used for monitoring simulated areal hydrological information from watersheds. For hydrological monitoring the interface provide large amount of otherwise hardly available data in real time, for example soil and lake evaporation, daily snowmelt, soil moisture. For water quality monitoring watershed models and this user interface provides a huge amount of simulated discharge and runoff data, which is otherwise impossible to obtain.

Internet

To Internet are delivered point forecast for water level and discharge for over 50 sites in Finland. Those forecasts are updated, when a forecast run is done. The Internet is the most effective delivery system used with watershed models. Forecasts are available for nearly all possible users and the system is reliable. Also the quality of the forecast pictures are better in the Internet than in other delivery systems.

The watershed model system creates also real time hydrological maps of Finland from which water balance terms can be followed. These maps are available for areal precipitation, soil evaporation, water equivalent of snow, daily snowmelt, soil moisture deficit, runoff (Fig. 3) and water level.

Connections to Other Systems and Research

The main use of lake inflow forecasts is the management of regulated lakes. Watershed models could also be very effective tools in general water resources planning; however they are seldom used for it at present. The problems arising with low-flow periods, e.g. water supply during droughts have also been solved by watershed models in a few cases.

The automatization of ice correction evaluations for discharges is a development project in which watershed models are tested to help; the corrected data are stored into HYTREK. This work has been presented by Leppäjärvi (1992) and Huttunen et al (1998).

In the case of observation break-ups in water levels and discharges the simulated data from watershed models can be used to fill the gaps in registers. Further more, the comparison between model simulations and observation data quickly reveals most of the observation and recording errors; thus watershed model simulations can be used as first quality control for data in registers.

Contrary to what was previously believed, pollution due to agriculture and forestry has proved to be much more important than point-source pollution (Rekolainen 1993). The evaluation of rural pollution from agriculture and forestry needs runoff and discharge data from relatively small areas. Watershed models, which simulate discharges for small sub-basins (50 - 500 km2), are very valuable information sources in this context. A real-time monitoring system for diffuse and point loads is under development. One of the discharge information sources of this system will be WSFS.

Large watershed models have been used lately in Finland and Nordic countries to evaluate the effects of climate change on water resources, especially on snow cover, discharge and water level changes. Results of these studies have been presented by Vehviläinen et al. (1991, 1997) in Finland and Saelthun et al. (1990, 1998) in Norway and Nordic countries.

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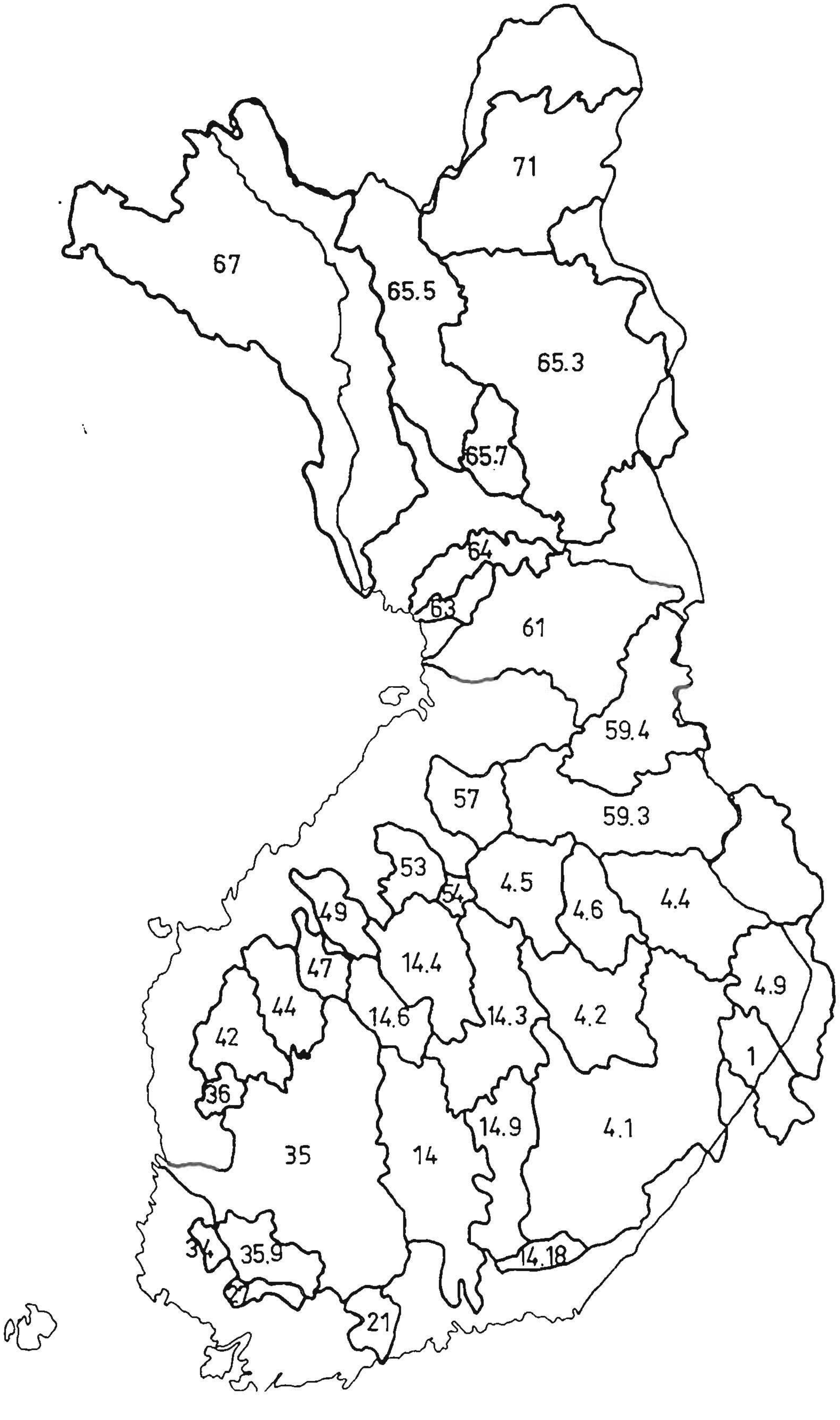
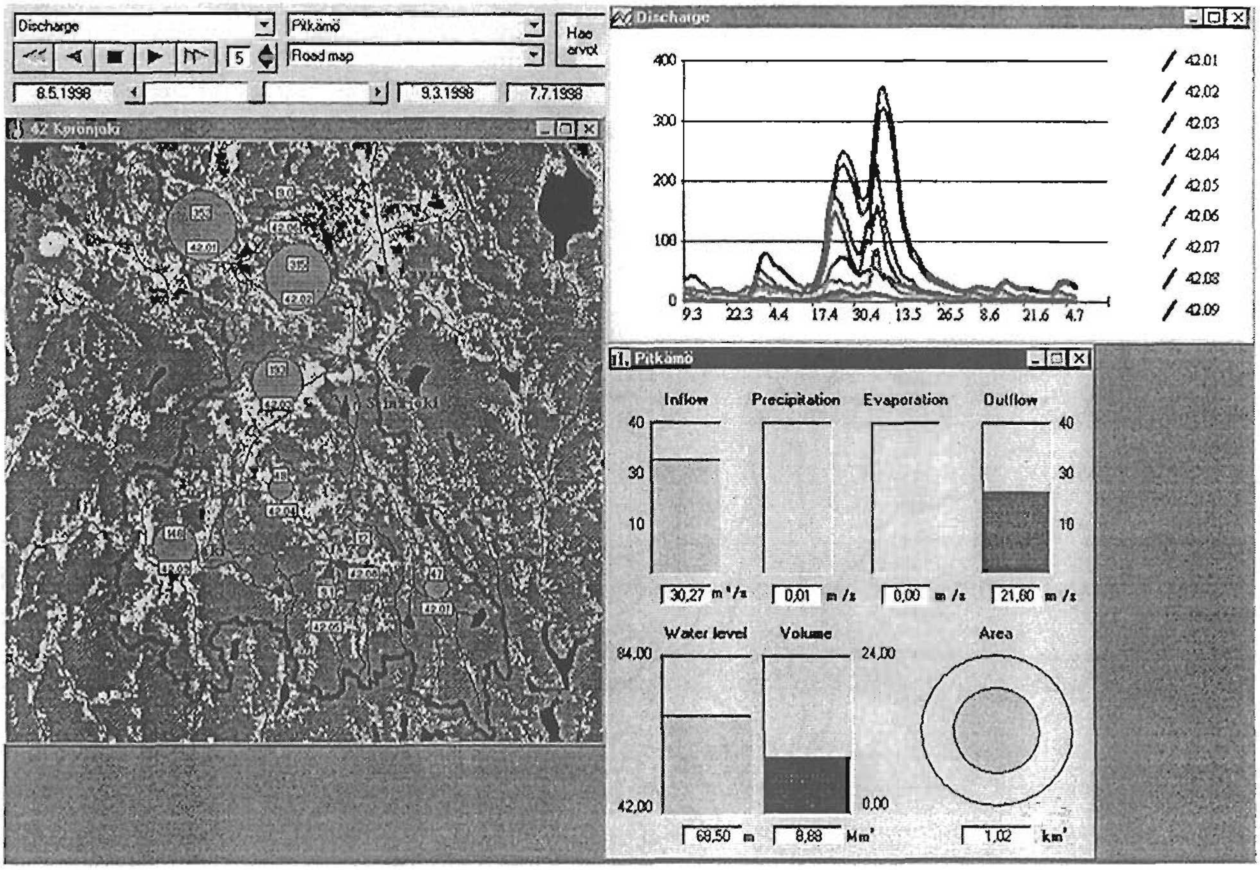


Figure 1. Watershed models in use. See Table 2 for more information..



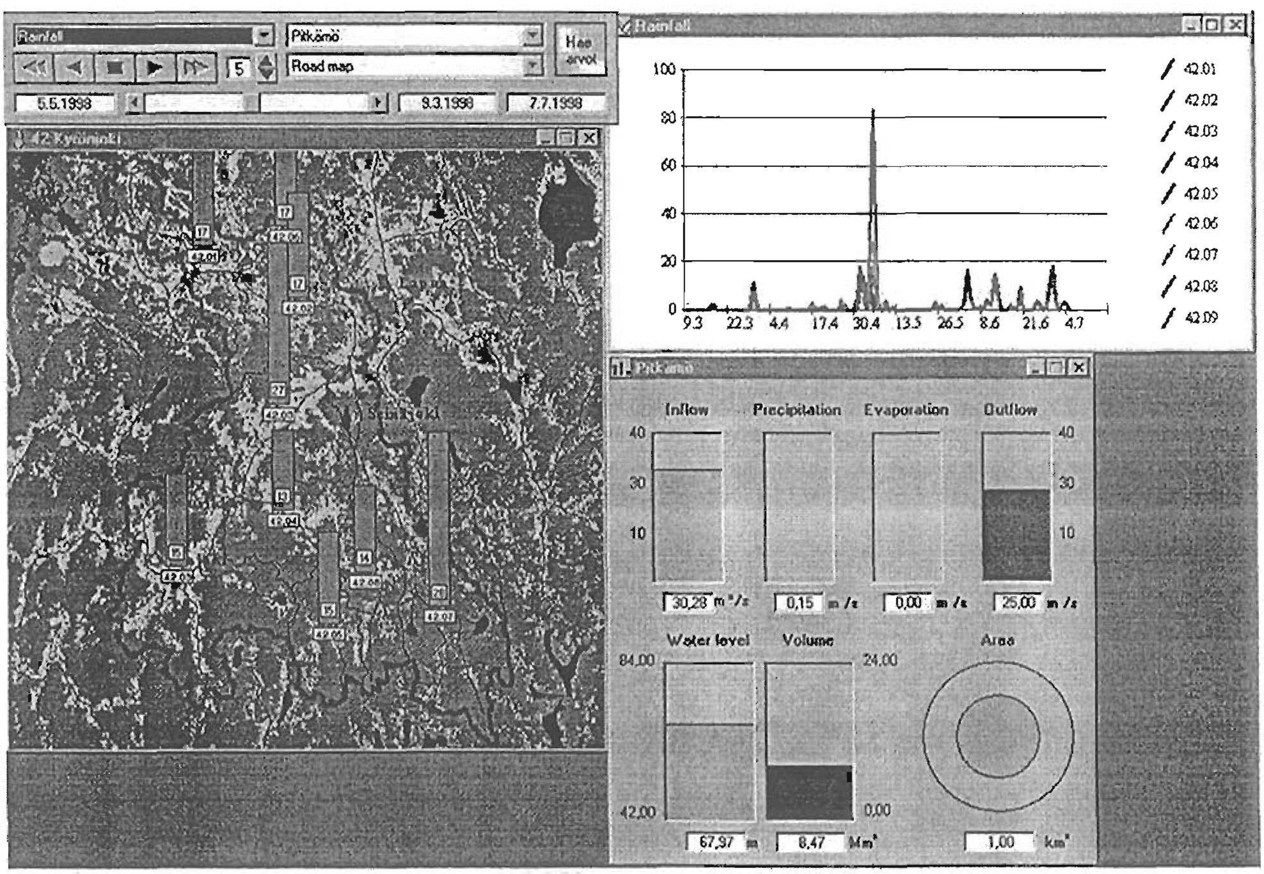


Figure 2. Discharge and rainfall data windows of map-based user interface from the basin of Kyrönjoki.

3. THE HBV MODEL IN NORWAY

By Dan Lundquist, GLB

At present the HBV model exists in many different versions in Norway. It can be found as part of heavy workstation applications under Unix or as lighter spreadsheet versions in Excel. As an example the following applications can be identified:

- Flood forecasting by NVE, using their own version
- Runoff prediction by hydro power companies, using the ID-version
- Climate change studies, using a Nordic model version
- Human influence on flood regimes by the HYDRA-project, using the PINE-version
- Model development by the project "New generation of hydrological models", using both the PINE-version and ECOMAG
- Energy sales, using local HBV-versions for predicting available water resources on a national scale
- National water balance mapping, using a distributed version of the HBV-model
- SnowView, a system for handling satellite data, field measurements and HBV-simulations
- FlowView, a system for decision support under development, where the HBV-model may be a future option
- Automatic calibration of the HBV-model, using PEST (the Parameter ESTimation program)
- Studies of the interface between meteorological and hydrological models, GCMs and HBVs.

After the introduction of the HBV-model in Norway in 1975, a significant amount of changes has been made to the model. The ID-version contains the following properties, not available in the original version:

- Division in two different zones, mountains and forest (above/under the timber line)
- Uneven snow distribution in each individual elevation zone
- Degree-day-formula with separate terms for radiatiative, convective and condensational contributions.
- Capillary withdrawal of water from the lower zone up into soilmoisture
- Lake routing within the catchment
- Use of observed temperature gradients
- Wind correction of precipitation values

Development Needs

The HBV-model as used today, in fact consists of two models, an input data model for precipitation and temperature, and the HBV-model itself, simulating the catchment response. Many different changes in the catchment response have been tested during the years, some resulting in increased performance, but most without significant improvements. In my opinion, one of the main potentials for increasing the performance of the HBV-model may be found in the input model. By introducing prevailing wind direction (or information on the actual weather type), I believe that both precipitation and temperature could be much better described than by the present simple weighing procedures.

Another problem with the HBV-model is that many parameters are inter-correlated. This can result in parameter combinations, producing nice runoff simulations, but with unrealistic values and thereby with small possibilities of checking internal variables by field measurements. One example is the snow melt algorithm that may look like this:

(Melt water) = (Snow-covered area) * CX * (T - TS)

If CX is given the wrong value, this can be compensated for by simulating an unrealistic snow-covered area (by toggling the snow distribution function). This obviously will lead to large problems when trying to match satellite mapped snow-covered areas with the HBV-model.

Glommen's and Laagen's Water Management Association

Glommen's and Laagen's Water Management Association (GLB), founded in 1918, is a co-operative of power station owners along the rivers Glomma and Laagen. The Glomma and Laagen catchment area covers 13 % of the land surface of Norway. With its 41 200 km^2 it extends 600 km from north to south and has an annual discharge of 22 000 mill.m^3. GLB consists of, and is owned by, a total of 20 industrial enterprises and hydroelectric power companies. These members have 44 power stations within the catchment area, which produce an average of 10 TWh annually. This represents 8-10 % of the average total Norwegian power production. GLB is responsible for 26 reservoirs and watercourse diversions, with a total storage capacity of approximately 3 500 mill.m^3. This is equivalent to 16 % of the runoff from the total river basin during an average year.

GLB runs approximately 150 monitoring stations. Manual observation and maintenance of instruments and equipment is taken care of by 15 dam attendants, a similar number of power station engineers and appr. 50 part-time employees. Appr. 70 of the observation sites are modern monitoring stations equipped with automatic recording devices and telephone answering machines. Many of these provide continuous on-line information on parameters such as water level, discharge, precipitation, temperature, snow depth and wind conditions.

GLB has developed information and calculation systems for estimation and prediction of the available water supply, including drainage from snow and glacier areas, and for estimation of the water level in, and the release from, each reservoir. Data on discharge, precipitation, temperature, snow depth, and groundwater levels from the catchment area are collected and matched with daily weather forecasts from the Norwegian Meteorological Office. On this basis hydrological models are used to calculate the probable short and long-term scenarios.

The possibilities for GLB to comply with the wishes of its members or other bodies are to a great extent dependent on the actual weather conditions. In planning, GLB must also take into consideration the possibility of future extreme situations such as floods and droughts. In long-term planning the needs and wishes of the members are important. Short-term planning is based on a combination of long-term strategies and short-term forecasts. According to the licensing conditions, GLB has an independent responsibility and authority during floods and other emergency situations. Especially during floods in springtime, the operation of the regulated reservoirs can have a significant flood reducing effect, even in a catchment as poorly regulated as the Glomma and Laagen river basin. This was clearly demonstrated during the extreme flood of 1995 (Lundquist & Repp, 1997).

Use of the HBV-model at GLB

Important tools for operating the regulations are a database and a river basin model. In the Glomma and Laagen river basin, GLB has calibrated 34 rainfall-runoff models, which describes the runoff conditions in all subcatchments to regulated reservoirs and to key points along the main river (fig.1). The model used is the swedish HBV-model, which is widely used in all the Scandinavian countries. These HBV-models are linked together by a routing model developed at GLB. This routing model describes the regulation of reservoirs, water transfers, and transport times. With this model it is possible to evaluate alternative release strategies for the reservoirs and its consequences further downstream. The HBV-version used at GLB is originating from the earlier KARMEN-version at NVE. The models are run at least once a week during normal situations, and more often during floods.

When forecasting the following procedure is followed:

- Update all the HBV-models to present date using Kalman filter techniques.
- Run the model for the next 7 days using the available quantitative meteorological forecasts.
- Run the model further with input from the last 20 years of historical met-data (fig.2).
- Calculate an average or a mean runoff series or choose one individual year.
- Adjust releases from reservoirs according to the chosen runoff scenario, starting at the upstream end of the basin.

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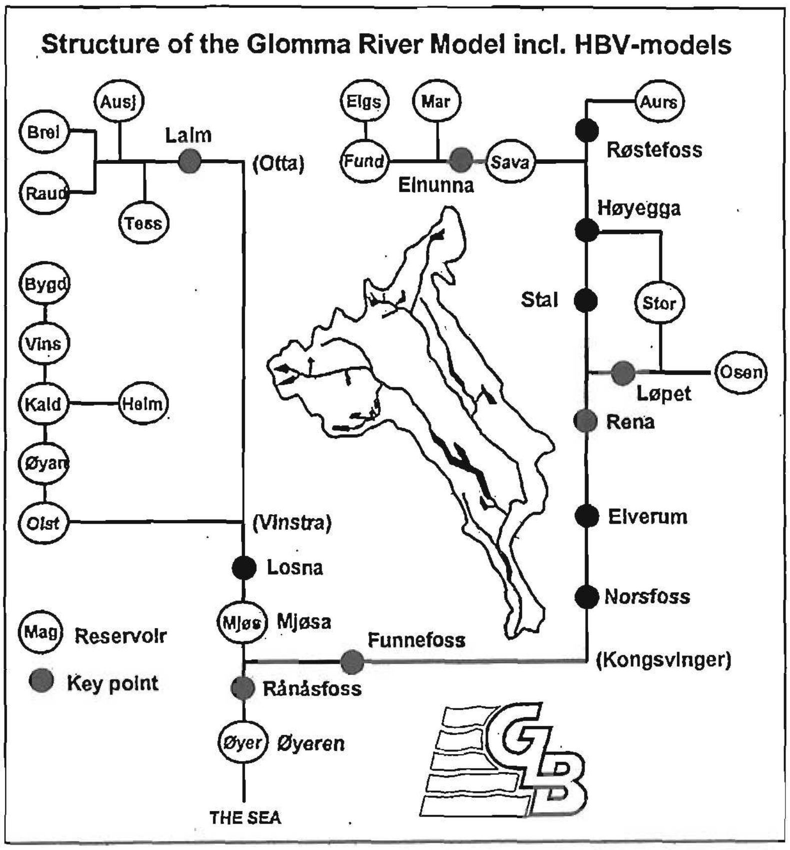

Figure 1. Structure of the Glomma River Model.

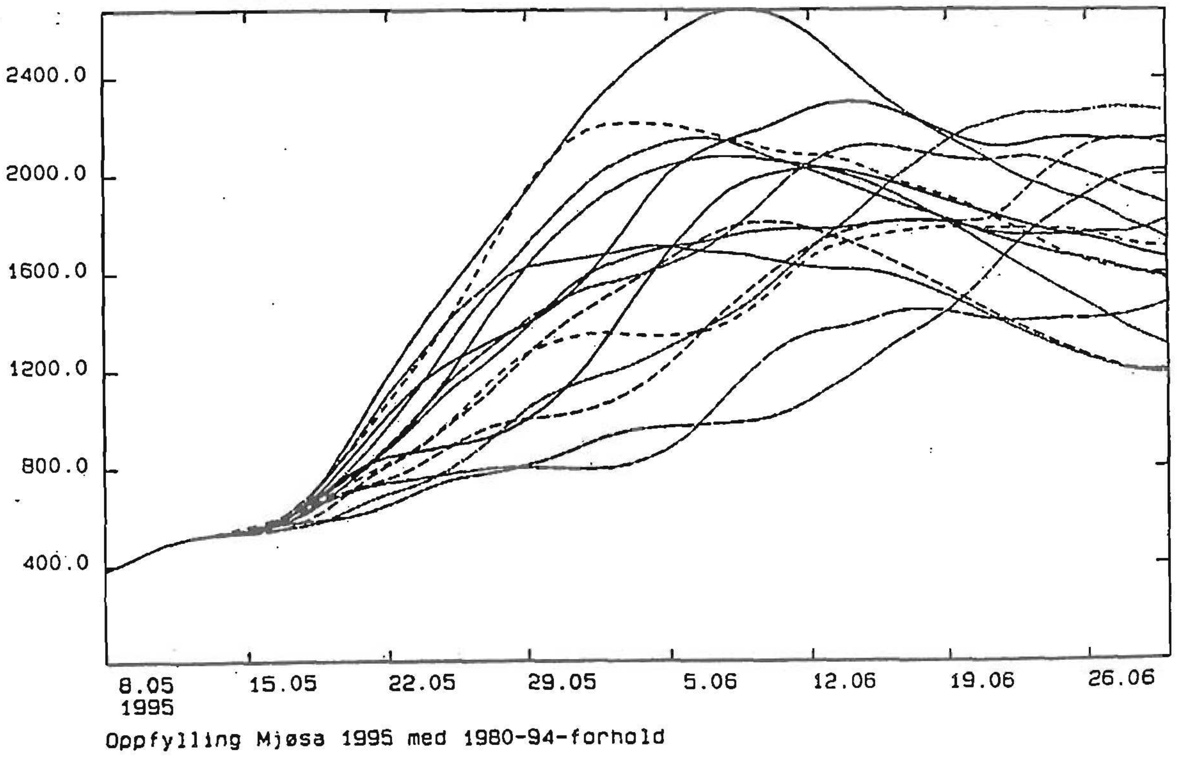

Figure 2. Example of a "spagetti-plot".

4. QUANTIFYING UNCERTAINTY IN HBV RUNOFF FORECASTS

Elin Langsholt (egl@nve.no)
Norwegian Water Resources and Energy Directorate (NVE)
Pb. 5091, Majorstua
0301 Oslo

Introduction

The HBV model is used as a flood-forecasting tool at NVE. The uncertainty associated with a flood forecast is important for risk assessment, and should be taken into account in the decision making process. For example, the probability of exceeding a certain critical level within the next day (fig. 1) may be more interesting for a decision maker than the precise expected level of the flood. It is thus useful to be able to quantify this uncertainty and to incorporate it as a part of the forecasting and flood warning routine.

Based on a study of the flood in Glomma in spring 1995, Lundquist (1997) lists the following elements as important sources for this uncertainty: meteorological forecasts, the rainfall-runoff model, initial conditions of the rainfall-runoff model, transport time, temporary loss of water and discharge rating curves. Here, the first two aspects of this list is studied: the uncertainty due to errors in precipitation and temperature forecasts and to the approximations of the natural processes performed by the rainfall-runoff model, namely the HBV model. The study is a part of the HYDRA program and is made in co-operation with Norwegian Computing Center.

The Method

The study includes three steps. First, a statistical method for assessing the uncertainty in the HBV model has been developed (Langsrud et al., 1998a). Next, the uncertainties in the meteorological forecasts have been considered (Follestad and Høst, 1998). And, finally, assuming that these two aspects are the sole sources of errors, a combination quantifies the composite uncertainty in runoff forecasts (Langsrud et al, 1998b).

The method can be implemented for routinely simulations of uncertainty of the HBV model forecasts. At NVE, forecasts are made for up to six days ahead, $j = 1, \ldots, 6$, and the errors can be decomposed into two parts:

$$\left(Q_{OBS}(t) - Q_{FOR}^{(j)}(t)\right) = \left(Q_{OBS}(t) - Q_{SIM}(t)\right) + \left(Q_{SIM}(t) - Q_{FOR}^{(j)}(t)\right) \qquad (1)$$

where Q_{OBS} is the observed runoff, $Q^{(j)}{}_{FOR}$ is the forecasted runoff j days ahead, i.e. the model calculated runoff based on forecasted precipitation and temperature, Q_{SIM} is the simulated runoff, that is the model calculated runoff based on observed precipitation and temperature and t is the time index. The first term on the right hand side is the HBV model error, and the second term is the error due to the uncertainty of the meteorological forecasts for temperature and precipitation. Future Q_{OBS} and Q_{SIM} are of course unknown, and we treat the equation statistically to develop distributions of these variables.

In the first step of this study, a statistical model for the HBV model error, $Q_{OBS}(t) - Q_{SIM}(t)$, was developed. This is an autoregressive model; i.e. the error today depends on the error yesterday, denoting today as t :

$$d_t = \alpha_t \, d_{t-1} + \sigma_t \, u_t \qquad (2)$$

where

$$d_t = log(Q_{OBS}(t)) - log(Q_{SIM}(t)), \qquad (3)$$

u_t is standard normally distributed and α_t and σ_t are functions of today's specific meteorological conditions. We use this model to develop an estimate of the distribution of the unknown $Q_{OBS}(t+1), \ldots, Q_{OBS}(t+6)$. This distribution is estimated empirically by running a set of Monte Carlo simulations (here 1000 runs have been applied) based on synthetic data for temperature and precipitation, $T^*_{t+1}, \ldots, T^*_{t+6}$ and $R^*_{t+1}, \ldots, R^*_{t+6}$. These meteorological data are drawn from a distribution according to Follestad and Høst (1998), developed during the second step of this study. By treating each meteorological sample as real data, the HBV model are run to produce future Q_{SIM} values, denoted by $Q^*_{SIM}(t+1), \ldots, Q^*_{SIM}(t+6)$. Now, by applying the model *(2)* and *(3)* and the synthetic temperature and precipitation data, we are in a position to estimate the future Q_{OBS} values, $Q^*_{OBS}(t+1), \ldots, Q^*_{OBS}(t+6)$, and an estimate of the first term on the right hand side of equation *(1)* can be made.

The distribution of the component of the runoff forecast error that is due to the uncertainty of the meteorological forecasts, $Q_{SIM}(t) - Q^{(i)}_{FOR}(t)$, follows from the distribution of temperature and precipitation (Follestad and Høst, 1998). The statistical models for temperature and precipitation are developed on historical data and include parameters that are dependent on the present meteorological conditions.

Results

The method has been applied to two catchments in Norway, representing two different hydrological regimes, see fig. 2. Røykenes in Western Norway has an area of 50 km². The annual mean flood, which is the arithmetic average of the annual maximum flood, is estimated to 51 m³/s. Large runoffs at Røykenes often occurs during autumn or winter, due to heavy rain. The catchment of Knappom is located in Eastern Norway and has an area of 1625 km². The estimated annual mean flood is 178 m³/s, and flooding is likely to occur from a combination of snowmelt and rain during spring.

The major component of the uncertainty of the runoff forecast differs among the two catchments. For Knappom, the HBV model error is the major term. Figure 3 shows that there is a high potential in improving the model calculated runoff by modelling and correcting for this error, as the median line of the estimated confidence interval follows the observed runoff much more closely than the simulated runoff. At Røykenes, the uncertainty in the weather forecasts is the heaviest contribute to the runoff-forecast error, and negligible improvements are made by correcting for the model error (fig. 4). This difference between the Røykenes and Knappom catchments may have connection with the size of the catchments, as the representativity of the areal precipitation estimate is generally poorer for smaller catchments.

With the current hardware and implementation of the algorithm, it takes about ten minutes to quantify the uncertainties for forecasts made one day for one catchment.

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Figures

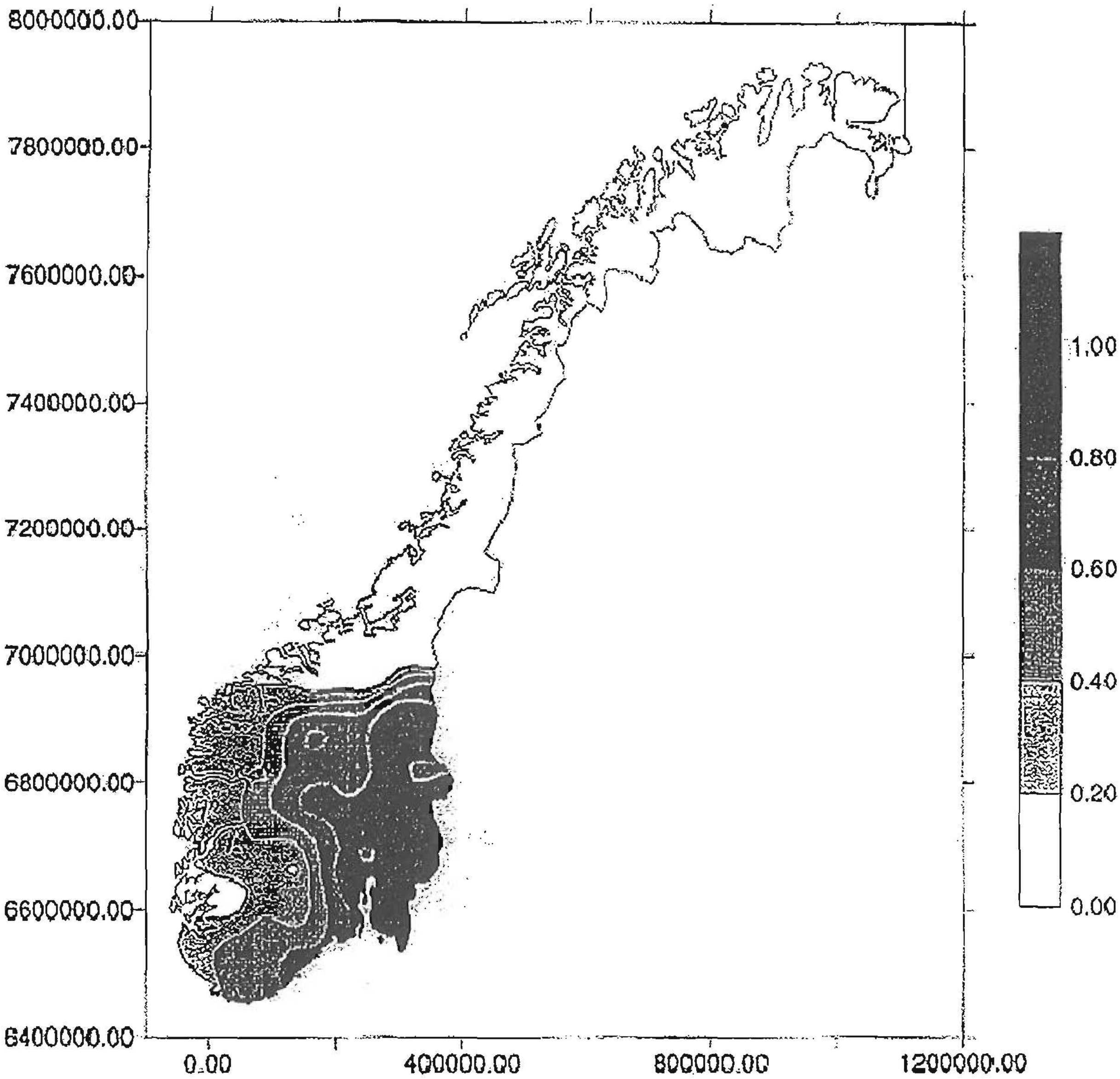

Figure 1. A map of Norway showing the distributed probability of exceeding the 10-year flood for a specific situation.

	Røykenes	Knappom
region:	Western Norway	Eastern Norway
area:	50 km^2	1625 km^2
mean annual flood:	51 m^3/s	178 m^3/s
flood season:	autumn/winter	spring

Figure 2. Location and data for the two test-catchments Røykenes and Knappom.

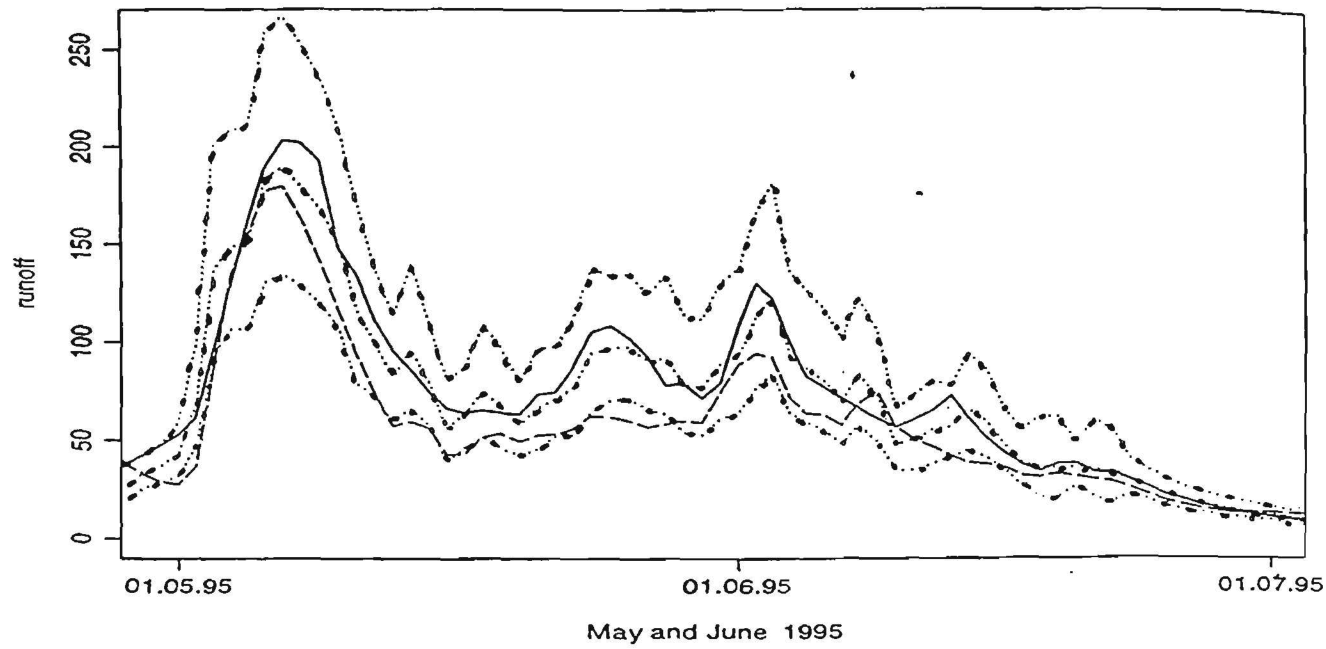

Figure 3. Confidence intervall for the HBV model error for Knappom: lower, upper and median values in a 95% interval (dot-dashed) together with $Q_{SIM}(t)$ *(long-dashed) and* $Q_{OBS}(t)$ *(solid) in May - June 1995.*

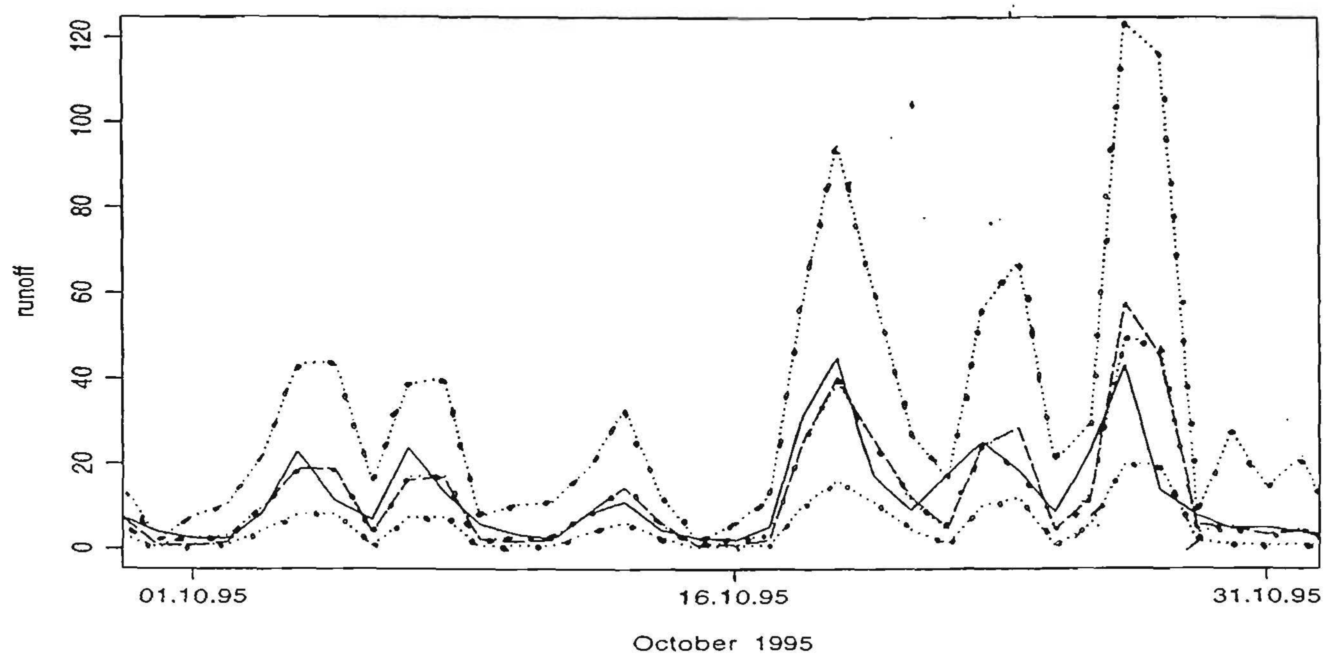

Figure 4. Confidence intervall for the HBV model error for Røykenes: lower, upper and median values in a 95% interval (dot-dashed) together with $Q_{SIM}(t)$ *(long-dashed) and* $Q_{OBS}(t)$ *(solid) in October 1995.*

5. PINE – A WORKBENCH FOR HYDROLOGICAL MODELLING

Trond Rinde
SINTEF – Civil and Environmental Engineering
Klæbuveien 153, N-7034 Trondheim, Norway

Simulation tasks within water related problems have become more complex and interdisciplinary. Modelling approaches are therefore required that can:

- Allow particular adaptation of simulation models to specific problems.
- Incorporate knowledge and process algorithms from several scientific disciplines in integrated simulation schemes.
- Support easy development and integration of new process algorithms.

A simulation tool called PINE (**P**rocess **I**ntegrating **Ne**twork) has been developed in order to meet these requirements (Rinde 1998). PINE is a configurable modelling tool that offers freedom in choice of model structures and process routines. A simulation model is built by linking computational elements together in a network structure (Figure 1). To the computational elements, process routines are assigned which generate local states and responses (Figure 2). Process routines can have both lumped and distributed algorithms. Distributed response calculations can be achieved in co-operation with a GIS.

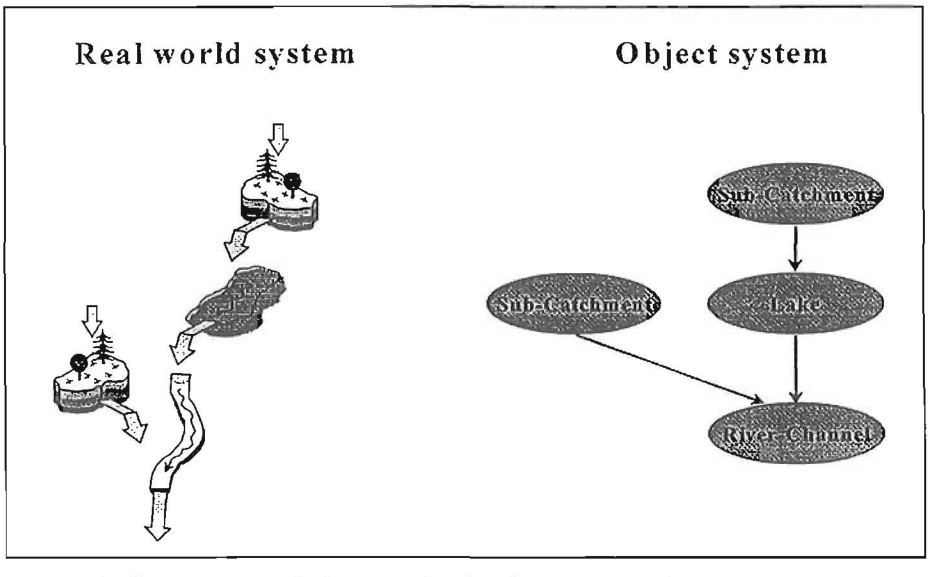

Figure 1. Computational elements in simulation network.

The system also supports integration of non-hydrological routines in hydrological simulation schemes. Algorithms for development in water temperatures, chemical constituents, algae growth, etc., can thus be included in simulation projects (Figure 2).

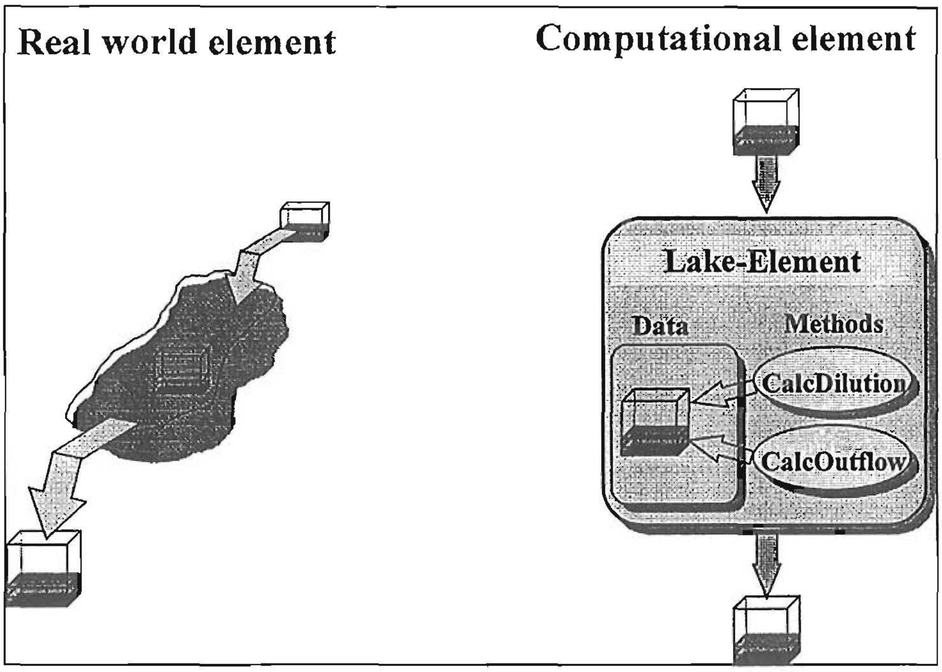

Figure 2. Process-routines in computational element.

The PINE-system is developed by use of object-oriented methodology. Separate program modules account for process topology, process responses, and process data (Figure 3). Each module is made dynamic, in order to support flexible configuration of model-setups at run-time.

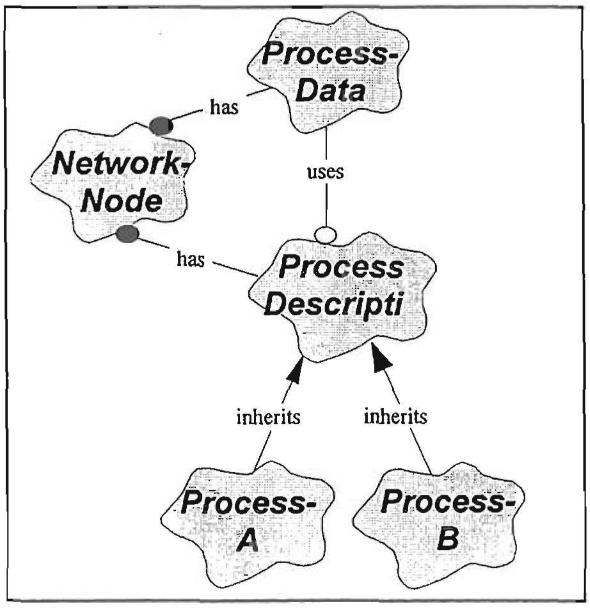

Figure 3. Class-structure

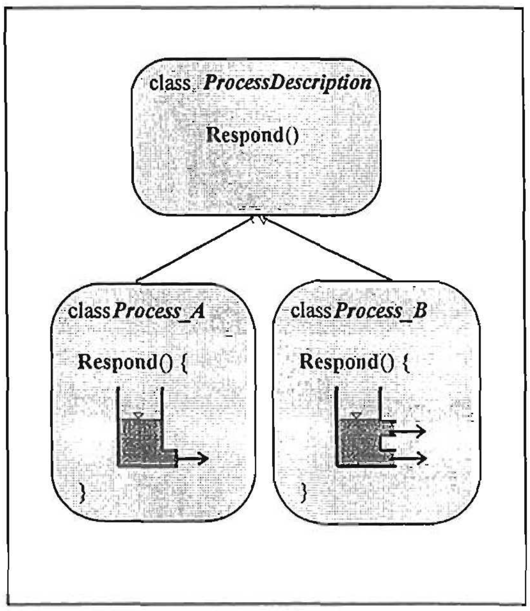

Figure 4. Process-description objects

The modularised program design facilitates very simple implementation of components for process responses. They only need to be filled with a response algorithm and definitions for the data elements that will be used. Development of new process routines is for this reason very simple (Figure 4).

HBV in PINE

Representing the HBV model in the PINE system only requires the algorithms of the model to be implemented as PINE process components. A simulation network reflecting the HBV structure may then be established. Figure 5 shows a possible HBV-representation in PINE. Extensive flexibility is here introduced compared to the original model. Users can add or remove snow nodes, soil nodes, or nodes for precipitation and temperature stations, or choose to describe one or more processes in a distributed fashion. It is thus possible to customise the model to special modelling tasks or to non-natural features in the catchments. For instance, routines may be introduced for diversions, reservoirs or hydropower stations, in order to allow simulation of regulated river systems. Distributed simulation methods for snow processes may allow direct comparison between simulated snow covers and snow covers extracted from aerial photographs or satellite images. This may facilitate a more precise updating of snow storage in the model, and thus lead to improved spring-flood forecasts.

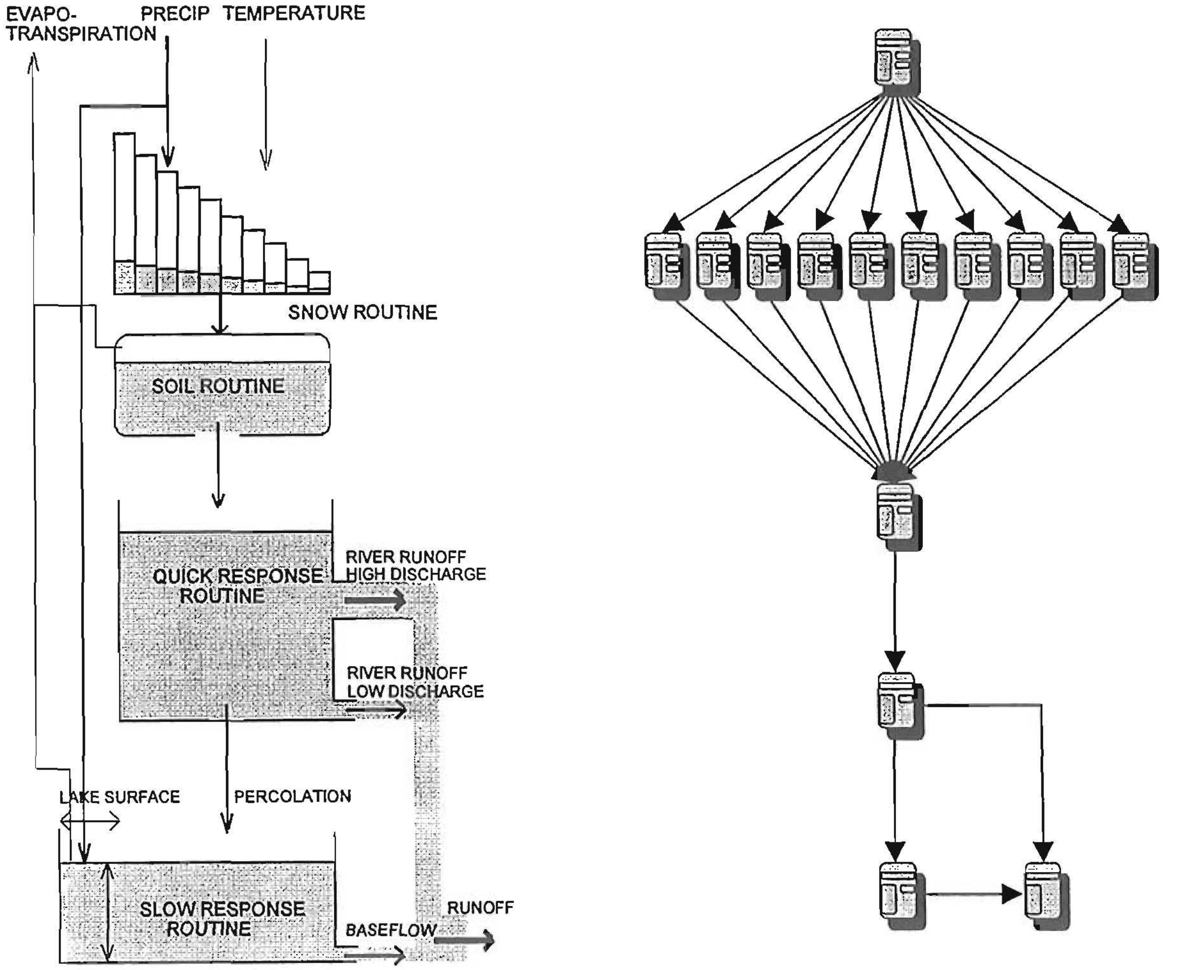

Figure 5 HBV-model implemented in PINE.

PEST – A Model Independent Optimisation Tool

PEST is a non-linear optimisation tool that can be used to calibrate a wide range of simulation models, hydrological models included (Brebber et al. 1994). PEST communicates with simulation models through the models own input and output files. The models do therefore not have to be modified in order to be calibrated by PEST, as long as they only can be run from the command line and execute without user interaction. In an optimisation process, PEST runs a model many times while adjusting its parameters until the discrepancies between some selected model output and a complementary set of observation data is reduced to a minimum. A particularly robust variant of the Gauss-Marquardt-Levenberg algorithm is used for the parameter estimation. Adjustment of control variables facilitates adaptation of the algorithm to particular models. In the optimisation process, model parameters can be constrained, fixed, or linked to other parameters. They can further be scaled, offset, or transformed in order to increase optimisation efficiency, or prior information about their likely values or interrelations can be incorporated to guide the optimisation process. Weights can furthermore be assigned to the observation data, in order to adjust the relative influence of different types of calibration data, or to account for varying quality within data series. At the end of an optimisation, PEST calculates statistical data for the optimised parameters. This includes 95% confidence intervals and parameter covariance and correlation coefficient matrices.

PESTCAL

In order to streamline automatic calibration of models implemented within the PINE system, a program system, PESTCAL, has been developed. This automatically sets up PEST for PINE models. As shown in Figure 6, PESTCAL works as a "front end" to PEST, where the users simply select the models they want to calibrate, and specify which catchments they shall be calibrated to, and which periods that shall be used. PESTCAL then generates a calibration-setup, and invokes the PEST program. When the calibration is completed PEST gives the control back to PESTCAL where the user can select new models, catchments, or calibration periods, and so on.

The PESTCAL system has currently been successfully used to calibrate HBV and a few other hydrological models to different Norwegian catchments (Rinde and Slettemoen Tøfte 1998). It has also been used to evaluate the performance of different versions of HBV.

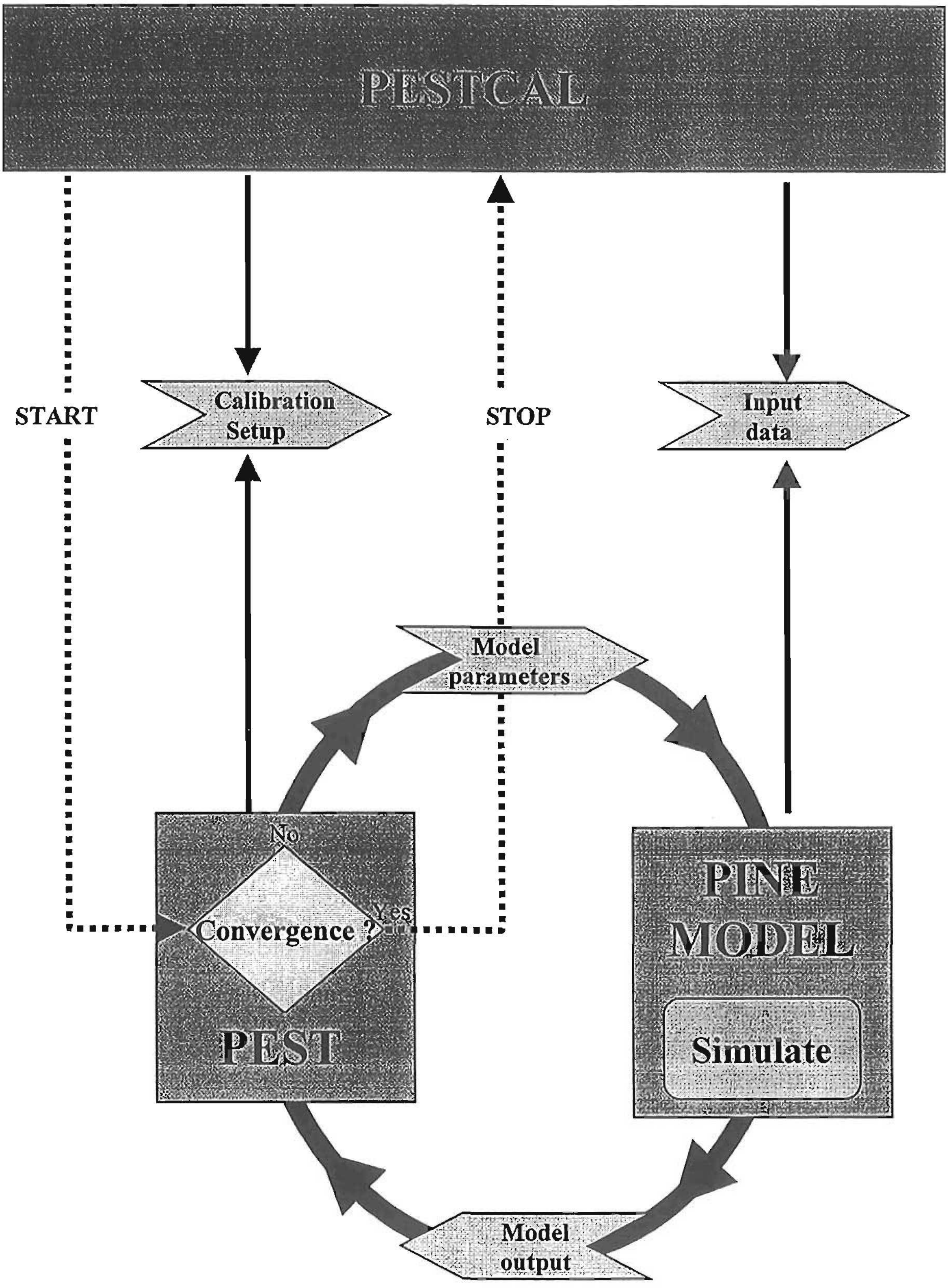

Figure 6. The PESTCAL system

Anthropogenic Influence on Flood Regimes in Norway – the HYDRA-project

In 1996, PINE was selected for the HYDRA project as a simulation tool for studying how changes in land use may affect on runoff regimes in rivers. One of the reasons for the choice was that the flexibility of PINE could be utilised to explicitly represent regions subjected to land use changes in simulation schemes. Comparative simulations would then become possible, which could quantify the effects of land-use changes in the regions. Another reason was that PINE allows representation of existing models, such as HBV (Bergström 1976) and SINBAD (Rinde 1993), which already is used in many natural and urban drainage areas in Norway.

The land use changes that were identified as particularly relevant with respect to influence on runoff regimes were afforestation and deforestation, agricultural development, and drainage of forests and marshes. In order to obtain an adequate representation of areas where land use changes may occur, it was decided to implement a fully distributed simulation model in PINE. This model should explicitly account for such processes as interception, evaporation, transpiration, and accumulation and melting of snow, as well as infiltration and generation of surface runoff on areas with different vegetation and surface characteristics. A modelling concept based on a grid-net partitioning of catchment areas was elaborated. In each grid cell the influences of high vegetation, snow, low vegetation, and land surface were explicitly described. The model structure for the grid-cell processes is shown in Figure 7.

The distributed calculation of the vertical water balance was then combined with a lumped method for groundwater flow and flow in rivers and lakes. The traditional response function of the HBV-model was here used. The total model structure is shown in Figure 8. If desired, flow responses can be differentiated for subcatchments according to the characteristics of the catchment under study. Outflow from various surface elements must then be aggregated separately for the subcatchments and addressed into individual routines for flow responses. This is illustrated in Figure 9.

Reports from the HYDRA project with model description and simulation results will be available within the end of 1999.

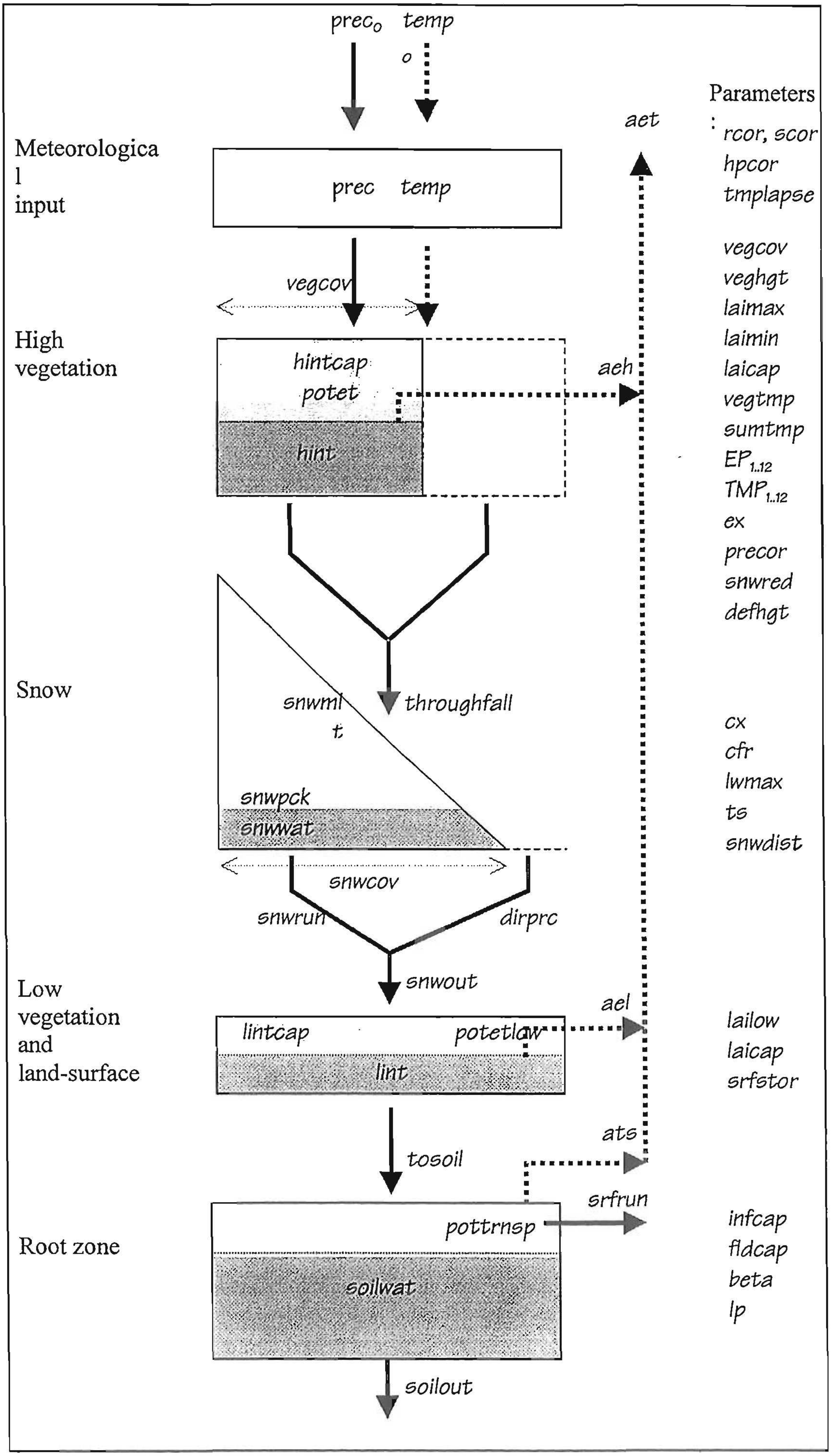

Figure 7. Model structure for grid-cell processes.

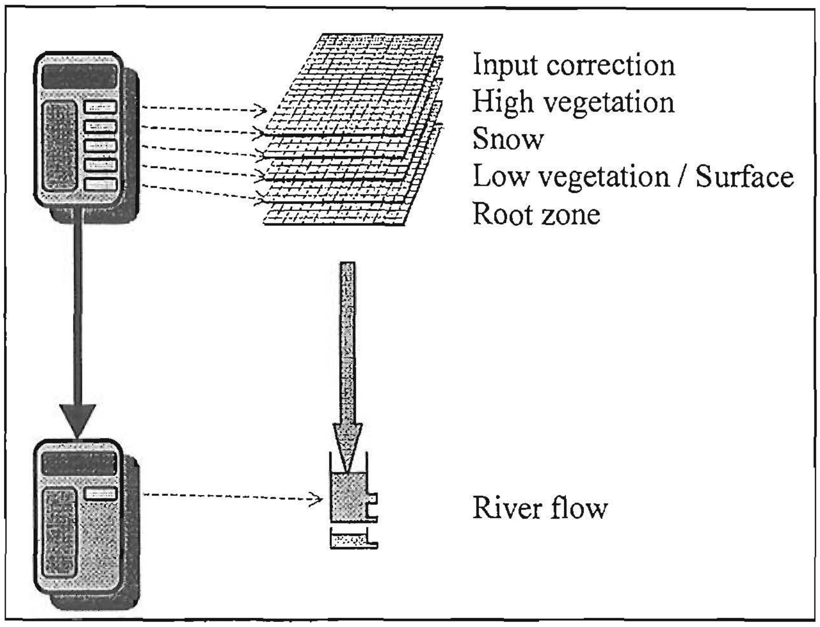

Figure 8. Land-use catchment model implemented in PINE.

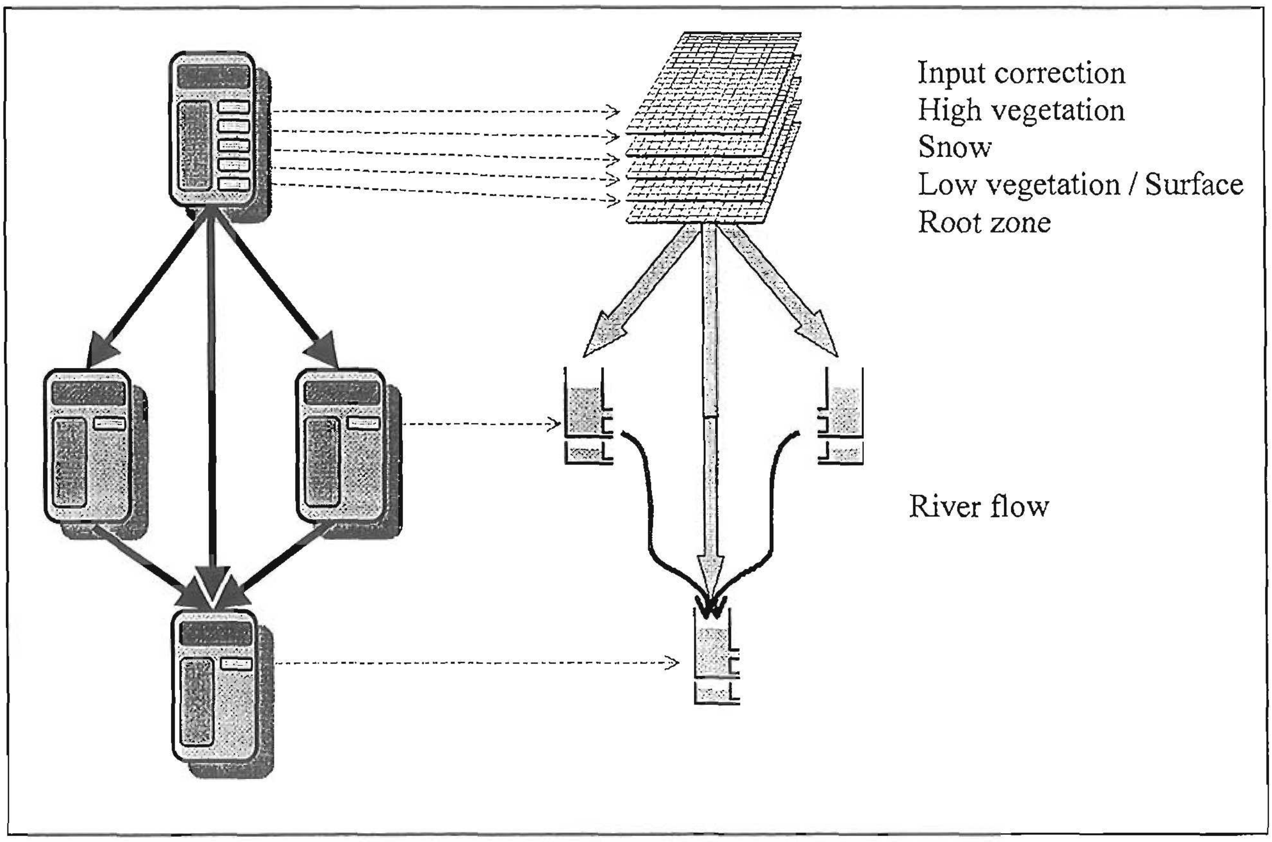

Figure 9. Land-use sub-catchment model implemented in PINE.

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6. NEW GENERATION OF HYDROLOGICAL MODELS

Kolbjørn Engeland,
Department of Geophysics, University of Oslo

Project Description

The project is aimed at developing methods and algorithms for spatially distributed rainfall/runoff models, including methods for precipitation estimation and new updating techniques. The project will run for three years with the objective to develop the issues mentioned above as main elements in a new generation of distributed rainfall/runoff models.

The work will partly be based on the development of gridded model systems for production of digital runoff maps at the Hydrological Department of the Norwegian Water Resources and Energy Administration (NVE), and partly the work on improved evapotranspiration modelling at the Department of Geophysics at the University of Oslo (models AMOR/HBVMOR/ECOMAG).

Further it will incorporate the model developments and the integration of remote sensing techniques developed at SINTEF Institute for Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU) - Department of Civil and Environmental Engineering, and NVE. The work on precipitation estimation will be based on the activities at the Norwegian Meteorological Institute (DNMI) aimed at establishing standardised and objective methods for precipitation correction.

The main objective of the project is not to develop full-fledged modelling systems, but more to establish submodels and algorithms that can be applied in general and specialised modelling packages. In the last part of the project period, pilot implementation will however be established, with the purpose to demonstrate the applicability and the practical usefulness of the results.

The main activities in the project are:

1. Improved description of winter conditions (i.e. snow redistribution, interception and evaporation, estimation of snow states)
2. Establish improved description of the seasonal influence of the vegetation on evapotranspiration and soil moisture content. Improve "gridpoint" (element) model.
3. Techniques for accumulation and routing of runoff from gridpoints through watercourse.
4. Objective methods for updating of model state variables in a gridded model from observations of runoff and from other observations.
5. Improved estimates of precipitation - correction of point observation errors and areal extrapolation.
6. Pilot implementations.

The project is part of the Research Programme "Grunnleggende energiforskning" ("Basal Energy Research"), Norwegian Research Council, and will run for the period 1998-2000.

A serious problem for validation of distributed model is the lack of spatial data, and it is chosen to establish a research area for testing of submodels and model structures. The upper part of the Glomma catchment is chosen as research area. The catchment has an area of 2411 km2, and is limited downstream by the gauging station Hummevoll north of Tynset. The area around the lake Aursunden is in focus, and in addition to existing hydrological and meteorological stations established new stations for measurements of precipitation, climate, runoff and soil- and groundwater. In addition a measurement campaign of runoff in 50 points has been performed. Several measurement campaigns for snow and runoff are planned. The area has a varied land cover (forest, mires, lakes, etc.) and deposits. The data will be used for mapping of spatial variability of runoff, snow and soil- and groundwater, evaluate evaporation calculations for different land covers and for validation of spatial distributed models. These in-situ-measurements will also be used for investigating the possibility for using remote sensing techniques for registration of the same values.

A gridded version of the ECOMAG model is developed and tested in the NOPEX area. (Motovilov & Gottschalk, 1999). The model describes the processes in the hydrological cycle and can be calibrated for internal variables like ground and solitaire measurements. The experiences from the NOPEX area are satisfying and are used as a starting point for implementation of the model for the Upper Glomma catchment. The area has several challenges having big variation in topography, vegetation and deposits. By calibration of the model for several catchments and several variables, the hope is to find a regional parameter set which makes it possible to use the model in ungauged catchments.

The ECOMAG Model Tested in the NOPEX Area.

Data

The model development was centred on data from the NOPEX experiment, performed north of the city of Uppsala in southern Sweden.

An extensive amount of meteorological and hydrological data collected during the NOPEX concentrated field efforts (CFE) CFE1 (27 May to 23 June 1994) and CFE2 (18 April to 14 July 1995) has been utilised in the process of setting up the model, its calibration and validation:

- Geographical data including a digital terrain model with a resolution of 50 m and land use data with 25 m resolution (both data sets from the National Land Survey of Sweden) and a comprehensive digitised soil map with a resolution of 2km (from Seibert, 1994).

- The regular hydrological discharge observation network runs by the Swedish Meteorological and Hydrological Institute (SMHI). The NOPEX area contains 10 standard gauging stations in drainage basins covering the main part of the area (Fig. 1) which provided 24 hour average values for the period 1981-1995.

- Data (daily values) from 25 precipitation stations, 7 temperature stations and 5 stations for vapour pressure deficit for the period 1981-1995 from the regular climatic observation network run by SMHI were used. The temperature and vapour pressure deficits were interpolated to a regular 2km grid by inverse distance weighting and the precipitation was interpolated by kriging.

- Detailed hydrological studies concentrated in five experimental basins (see Fig. 1 for location) during the NOPEX CFE1 and CFE2. These included measurements of discharge, groundwater levels and soil moisture as well as standard climatological variables. The sites for groundwater levels and soil moisture measurements were chosen to represent different geomorphologic units (hollow, slope, and nose) within the experimental basins. This data set comprises about 2000 individual measurements of groundwater levels and about 16 000 measurements of soil moisture content (the measurements were also performed outside CFE periods).

- Synoptic discharge measurements at 38 sites in the Fyrisån river basin on four occasions during recession.

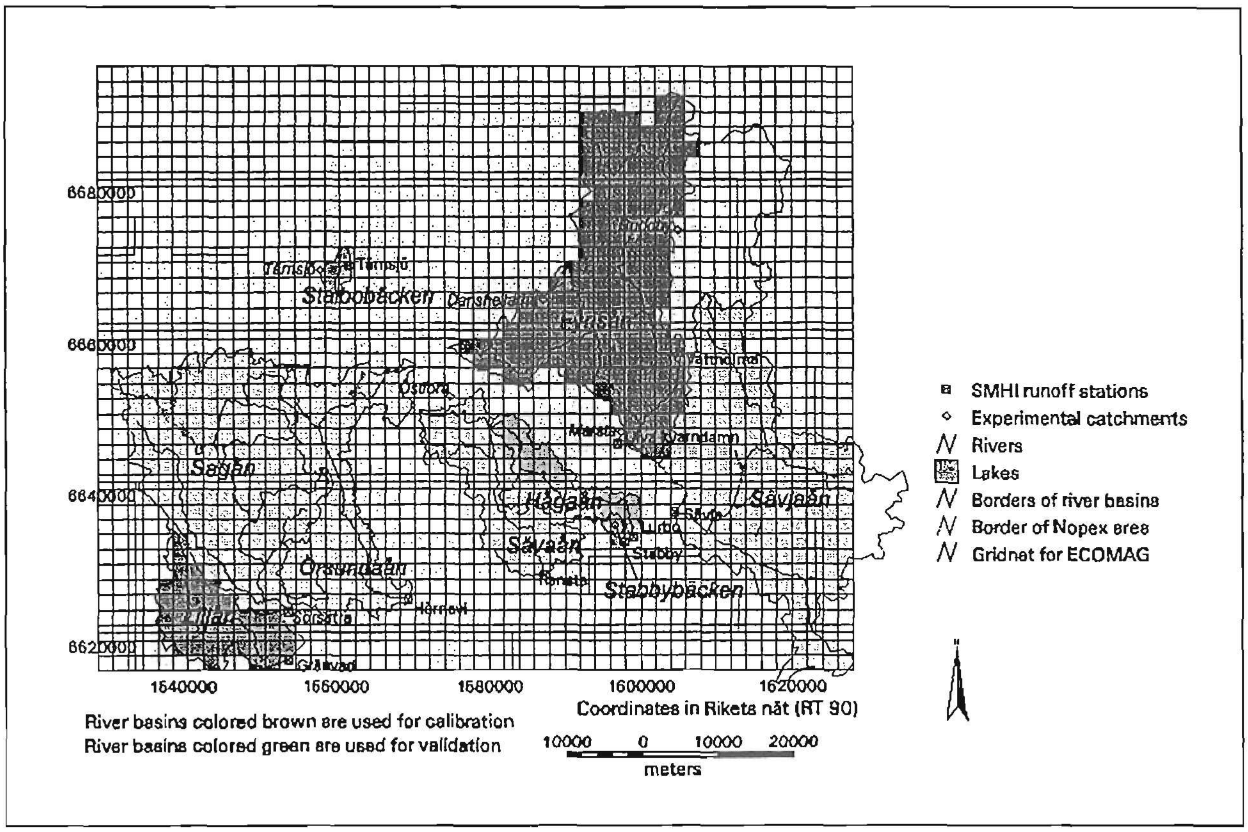

Figure 1. Ten gauged river basins and five experimental basins in the NOPEX area.

Scale Problems

In meteorology and also in subsurface hydrology there is a tradition of distinguishing between spatial variability at different scales. In surface hydrology it is quite a recent way of thinking. The concept of Representative Elementary Volume (REV) on which scale basic theoretical equations are founded is focal in this respect. Wood et al. (1988, 1990) has introduced the complementary concept of Representative Elementary Area (REA). At a certain scale a landscape element (a drainage basin or a grid cell) might contain a sufficient sample of the geomorphologic, soil and other relevant characteristics of the region. It is then no longer necessary to take account of the pattern of those characteristics but only of their distribution. The underlying variability may still be important in controlling both discharges and evaporation fluxes, but the patterns are less important. The scale at which this happens defines the REA.

Fig. 2 shows examples of plots used to identify the REA for terrain with till soils. The soil moisture and groundwater level data were obtained by the measurements in the NOPEX area during CFEs periods. A preliminary conclusion is that for this type of terrain the main part of the spatial variability in soil moisture and groundwater fluctuations is contained in the 2 km grid size used for modelling (Beldring et al., 1999). Theoretical distribution functions have been developed that can take into account this variability.

The possibility of identifying a REA is of vital importance for the process formulation in the ECOMAG model as it indicates that within a grid cell of 2km runoff is delivered to the river network and that rivers provide the only exchange between grid cells in this type of landscape. The exchange through groundwater flow is of negligible order, as there are no runoff formation factors acting at a between grid cell scale.

From the scale analysis it is obvious that measured soil moisture and groundwater level values cannot be compared directly with the corresponding modelled ones. The latter values do not reflect the full small-scale variability as illustrated by the left-hand side of the diagrams in Fig. 2. Measured data must be averaged to the REA scale to be able to match model output.

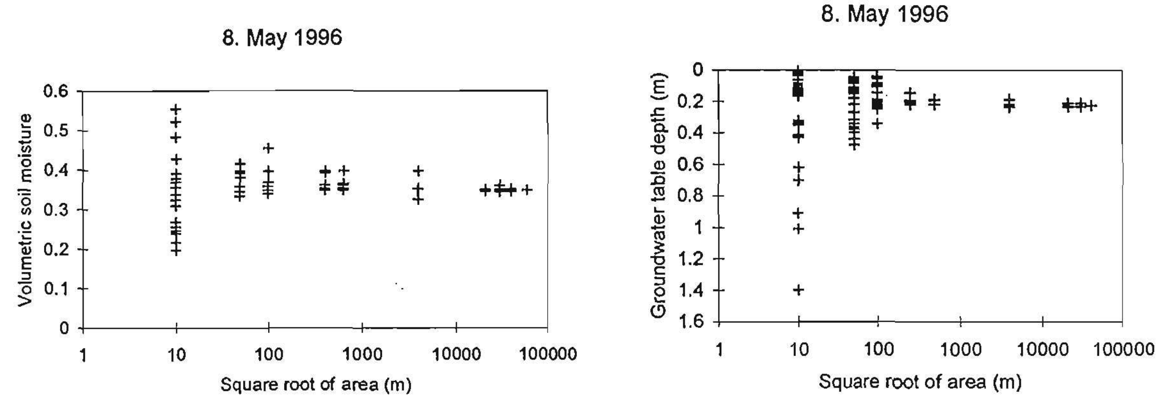

Figure 2. Spatial variations of soil moisture and groundwater levels as functon of scale of aggregation (from Beldring et al., 1999).

Hydrological Model Formulation

The distributed hydrological model ECOMAG (Motovilov and Belokurov, 1995; Motovilov et al., 1999) developed for application to boreal conditions was used. The model describes the processes of soil infiltration, evapotranspiration, thermal and water regimes of the soil, surface and subsurface flow, groundwater and river flow, snow accumulation and snowmelt.

The main change is the use of a regular grid network (2 km x 2 km) in order to, with further development, allow direct coupling with a meso-scale meteorological model and the use of radar-evaluated precipitation data (Crochet, 1997).

The basic assumption of the model is that a river basin can be sub-divided into a mosaic of irregular or regular elements, each to be viewed as a landscape hydrological unit. The REA concept referred to above is of vital importance here as it constitutes a minimum size for such an element. The specific characteristics of topography, structure of river network, soil types, land use etc. for each element are determined in a GIS framework.

The hydrological model for a landscape unit was constructed in conformity with the following scheme taking into account the processes of hydrological cycle (Fig. 3). During a summer period the rain partially infiltrates into the soil and penetrates into deeper soil layers. The soil is divided into a top layer (horizon A), an intermediate layer (horizon B) and a bottom layer (groundwater storage). The total porosity of the soil is divided into two parts: a capillary zone (the upper limit of which is the field capacity) and a noncapillary zone (the difference between total porosity and field capacity).

After the filling of depressions on the surface, the excess of water, not absorbed by the soil, runs off on the sloping land surface to the river network (surface flow). A part of the water, which was infiltrated into the soil, follows a temporary, relatively impermeable, boundary along the slopes as shallow groundwater (subsurface) flow. Another part is transported in the groundwater zone and forms base flow. The subsurface and groundwater flow is modelled as a Darcy flow, while the surface and river runoff is described by a simplified version of the kinematic wave equation (Rose et al., 1983).

Under the condition of high soil moisture content, the actual evaporation equals the potential, and then linearly decreases with the decay of the soil moisture content to a certain lowest level, being zero at the soil moisture content equal to the wilting point (Feddes et al., 1974).

Lake-element in the area is described as a storage with recession coefficient defined on the basis of the kinematic wave equation. The actual evaporation is taken equal to the potential one.

During cold periods of the year, the scheme is supplemented by hydrothermal processes - snow cover formation, snowmelt, freezing and thawing of the soil, and infiltration of snowmelt water into the frozen soil. The phase composition of precipitation is determined by the daily average air temperature. The snowmelt rate is calculated using the degree-day method. Evaporation of solid and liquid phases of snow is estimated using data on vapour pressure deficit.

It is assumed that the vertical temperature profiles in the snow as well as in the frozen and thawed soil differ only slightly from linear ones, and that the migration of moisture to the freezing front is negligible. Under these conditions the soil-frost and soil-thawing depth dynamics can be described by a system of ordinary differential equations (Motovilov and Nazarov, 1994). Infiltration of rain and meltwater into the frozen soil is calculated, taking into account the influence of ice content in the frozen soil on the hydraulic conductivity of the soil.

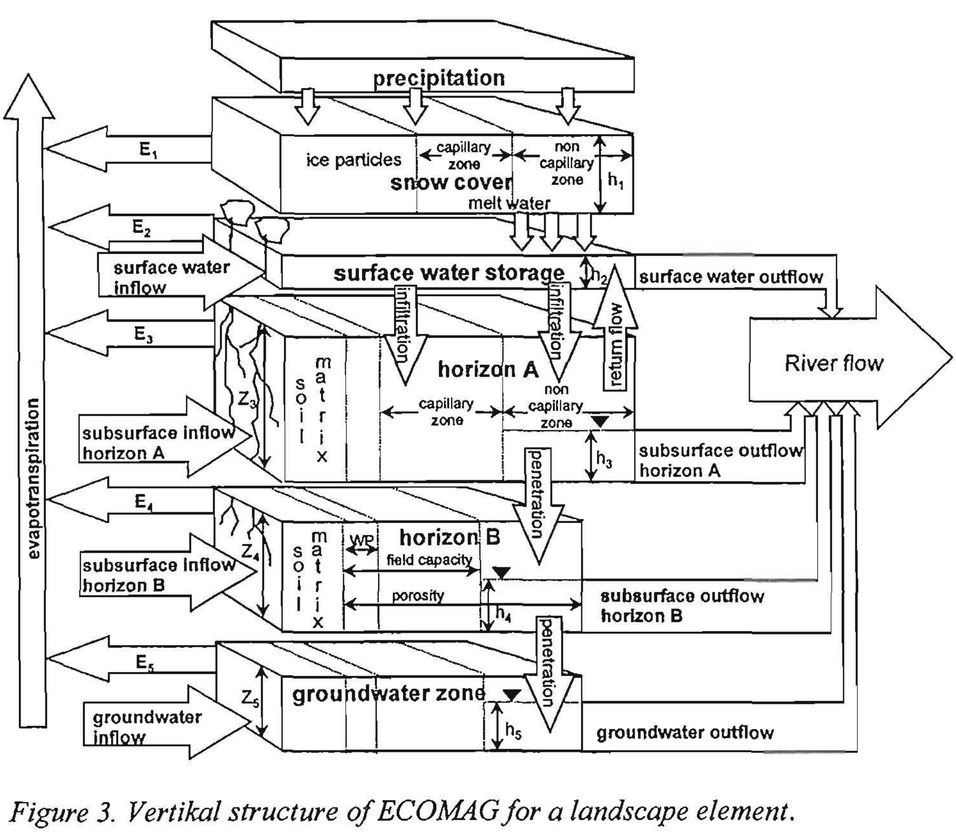

Figure 3. Vertikal structure of ECOMAG for a landscape element.

The landscape information extracted from the GIS only grasps large-scale features. Small-scale fluctuations in landscape characteristics, however, are important for the runoff formation processes. A common approach in lumped hydrological models is to resolve this variability in terms of spatial distribution functions (Kuchment et al. 1986). A simplification is to use the same distribution for all elements only allowing its mean value to vary between elements. In ECOMAG the within element variability is taken into consideration in this manner for three parameters - the vertical saturated hydraulic conductivity of soils, surface depression storage and soil field capacity. For the first two parameters an exponential function is applied (Vinogradov, 1988; Popov 1979) and for the third - a parabolic function (Bergström, 1976; Dümenil and Todini, 1992).

Most parameters of the ECOMAG model have a physical interpretation, for example soil physical parameters, which can, in principle, be measured. Others can be given reasonable values from experience, for example the degree-day factor. However, calibration of some model parameters is required to achieve an acceptable model performance. Table 1 shows the calibration parameters of the model. The question put forward here is whether a calibration of a global set of parameters on a few basins in a region provides acceptable performance for basins not used in the calibration and for variables not included in the calibration procedure. Evidence cited herein supports this minimal calibration with some caveats.

Table 1. Model calibration parameters

Snow routine
Degree-day factor
Threshold temperature*
Water holding capacity*
Parameter of snow compaction*
Soil routine
Depth of horizon A
Porosity
Field capacity
Wilting point
Vertical hydraulic conductivity
Horizontal hydraulic conductivity
Factor for potential evaporation*
Surface runoff routine
Surface retention storage
Surface roughness (Manning coefficient)
River runoff routine
River bed roughness (Manning coefficient)*

Parameters with asterisk (*) have one unique value for the whole NOPEX area, while the others have different values for different soil and land use types

The global parameters were determined from a joint calibration against runoff data for seven years from three drainage basins (Fyrisån, Lillån and Stabbybäcken) with an additional adjustment of soil parameters against soil moisture and groundwater level data from five small experimental sub-basins in 1994-1995 including CFE periods. The model with these parameters was then validated against runoff data for 14 years from six other basins and the remaining seven years for the three basins used for calibration, and against synoptic runoff measurements on four occasions in the largest drainage basin Fyrisån during CFE1 and CFE2. Finally, regional estimates of daily evapotranspiration were compared with estimates from flux measurements, to give an independent assessment of the water balance.

The performance of simulated runoff was evaluated by the Nash-Sutcliffe efficiency measure (Table 2). For the larger basins and for the NOPEX area as a whole the results were classed as good and for other basins as satisfactory. A striking result is the variation in the performance criteria between different years, which partly might be explained by shifts between stable and unstable winter climatic conditions. Some discrepancies in the model performance are suspected to be caused by poor quality in regular runoff data. However, the overall result must be considered to be good as the simulations were performed without calibration.

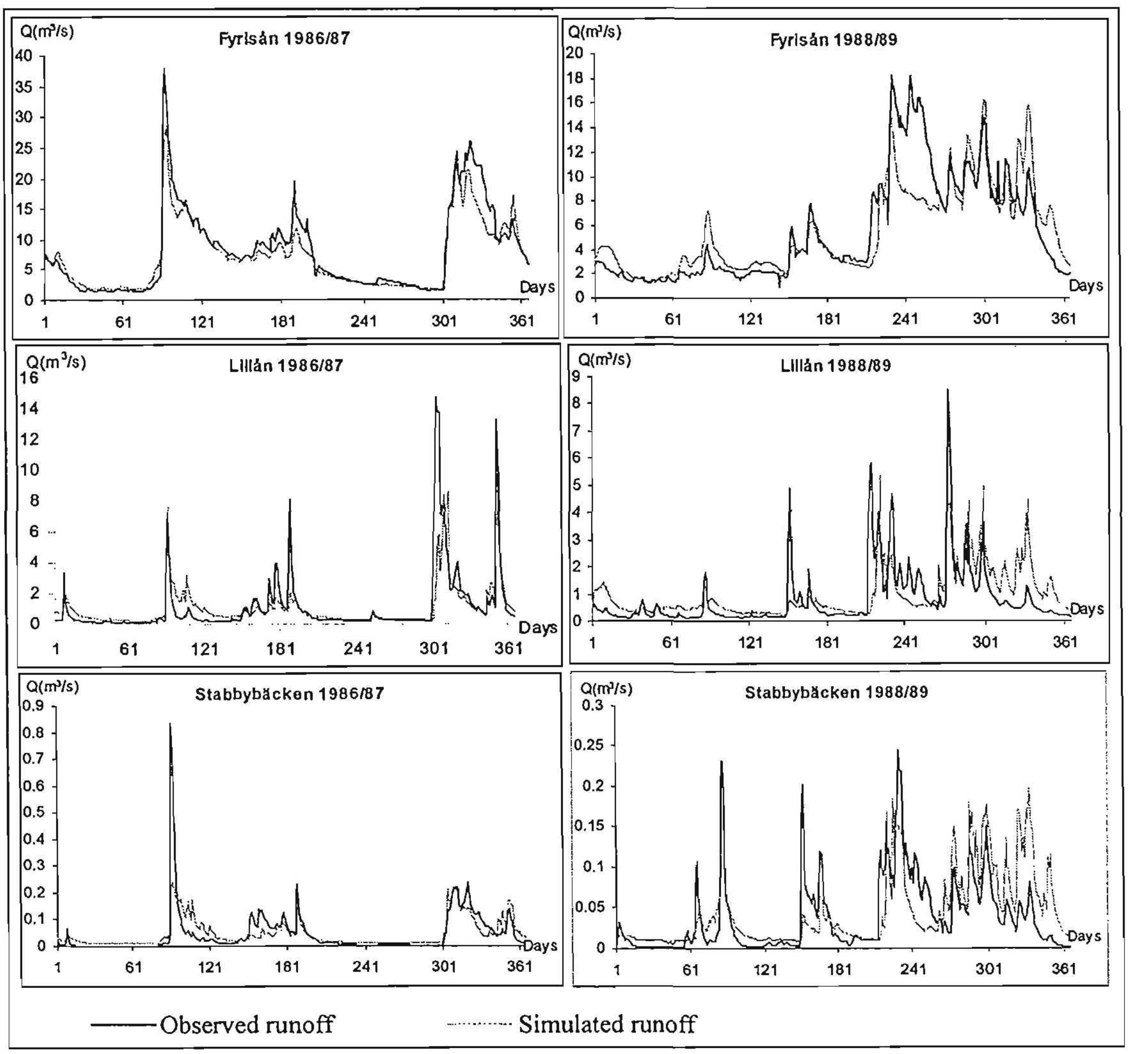

Figure 4. Model results for the stations used for calibration.

Table 2. Model performance efficiency (R^2) for the gauged river basins in the NOPEX area*

Year \ Basin	Fyrisån	Sagån	Lillån	Örsundaån	Hagaån	Sävaån	Sävjaån	Stalbo-Bäcken	Stabbybäcken	Total gauged area
1981/82	0.73 / 0.76	0.60 / 0.64	0.72 / 0.72	0.83 / 0.88	0.64 / 0.75	0.76 / 0.83	0.65 / 0.73	0.14 / 0.29	0.58 / 0.72	0.79 / 0.81
1982/83	0.81 / 0.84	0.56 / 0.60	0.62 / 0.70	0.52 / 0.73	0.43 / 0.83	0.62 / 0.80	0.53 / 0.61	0.70 / 0.72	0.59 / 0.60	0.76 / 0.80
1983/84	0.72 / 0.78	0.57 / 0.61	0.65 / 0.81	0.64 / 0.72	0.56 / 0.82	0.69 / 0.75	0.50 / 0.63	0.84 / 0.83	0.61 / 0.66	0.74 / 0.78
1984/85	0.78 / 0.84	0.83 / 0.86	0.75 / 0.90	0.84 / 0.94	0.77 / 0.96	0.90 / 0.96	0.82 / 0.93	0.75 / 0.88	0.68 / 0.93	0.90 / 0.95
1985/86	0.83 / 0.88	0.50 / 0.28	0.69 / 0.74	0.80 / 0.81	0.76 / 0.81	0.82 / 0.91	0.86 / 0.90	0.30 / 0.20	0.57 / 0.81	0.88 / 0.90
1986/87	***0.88*** / ***0.94***	0.48 / 0.46	***0.57*** / ***0.71***	0.69 / 0.72	0.53 / 0.71	0.73 / 0.84	0.69 / 0.77	0.45 / 0.54	***0.54*** / ***0.75***	0.77 / 0.79
1987/88	***0.86*** / ***0.91***	0.48 / 0.51	***0.72*** / ***0.85***	0.76 / 0.85	0.56 / 0.66	0.75 / 0.80	0.66 / 0.77	0.75 / 0.83	***0.57*** / ***0.77***	0.77 / 0.83
1988/89	***0.70*** / ***0.84***	0.25 / 0.33	***0.32*** / ***0.46***	0.22 / 0.60	0.26 / 0.64	0.27 / 0.64	0.19 / 0.58	0.62 / 0.76	***0.26*** / ***0.44***	0.48 / 0.68
1989/90	***0.91*** / ***0.93***	0.69 / 0.76	***0.66*** / ***0.77***	0.77 / 0.85	0.70 / 0.92	0.80 / 0.89	0.83 / 0.88	0.85 / 0.90	***0.75*** / ***0.91***	0.86 / 0.90
1990/91	***0.77*** / ***0.92***	0.35 / 0.19	***0.62*** / ***0.84***	0.62 / 0.74	0.53 / 0.62	0.71 / 0.78	0.60 / 0.65	0.60 / 0.68	***0.71*** / ***0.85***	0.72 / 0.75
1991/92	***0.80*** / ***0.87***	-	***0.60*** / ***0.77***	0.52 / 0.70	0.19 / 0.44	0.57 / 0.80	0.63 / 0.77	0.57 / 0.58	***0.44*** / ***0.70***	0.81 / 0.91
1992/93	***0.90*** / ***0.94***	-	***0.74*** / ***0.78***	0.71 / 0.73	0.64 / 0.78	0.65 / 0.72	0.78 / 0.85	0.73 / 0.79	***0.76*** / ***0.85***	0.84 / 0.87
1993/94	0.70 / 0.87	-	0.40 / 0.76	0.39 / 0.71	0.59 / 0.74	0.55 / 0.75	0.61 / 0.80	0.46 / 0.50	0.54 / 0.75	0.67 / 0.88
1994/95	0.72 / 0.78	-	0.61 / 0.78	0.53 / 0.91	0.24 / 0.70	0.69 / 0.91	0.69 / 0.84	0.67 / 0.66	0.65 / 0.95	0.80 / 0.92
1981-91	0.81 / 0.87	0.57 / 0.60	0.69 / 0.81	0.75 / 0.83	0.63 / 0.81	0.77 / 0.86	0.71 / 0.80	0.57 / 0.67	0.61 / 0.78	0.81 / 0.85
1981-95	0.81 / 0.87	-	0.67 / 0.80	0.71 / 0.83	0.60 / 0.80	0.76 / 0.85	0.71 / 0.81	0.59 / 0.68	0.62 / 0.79	0.82 / 0.88

* Numerator - R^2 day
Denominator - R^2 month

0.00 - data included in calibration.
0.00 - validation.

The ability of the ECOMAG model to simulate the variation of average soil moisture for grid 2km x 2km as showed by this study is also good. The performance has been evaluated by the Nash-Sutcliffe efficiency measure comparing averaged observed values for grid cells with those simulated. The performance is equally good for till, clay and sandy soils. Averaged observed and simulated groundwater level data have been compared in the same manner, with slightly poorer results than in case of the soil moisture. A problem here has been to obtain representative average groundwater level values for grids, because of the difficulties with installing access tubes to sufficient depth in till soils.

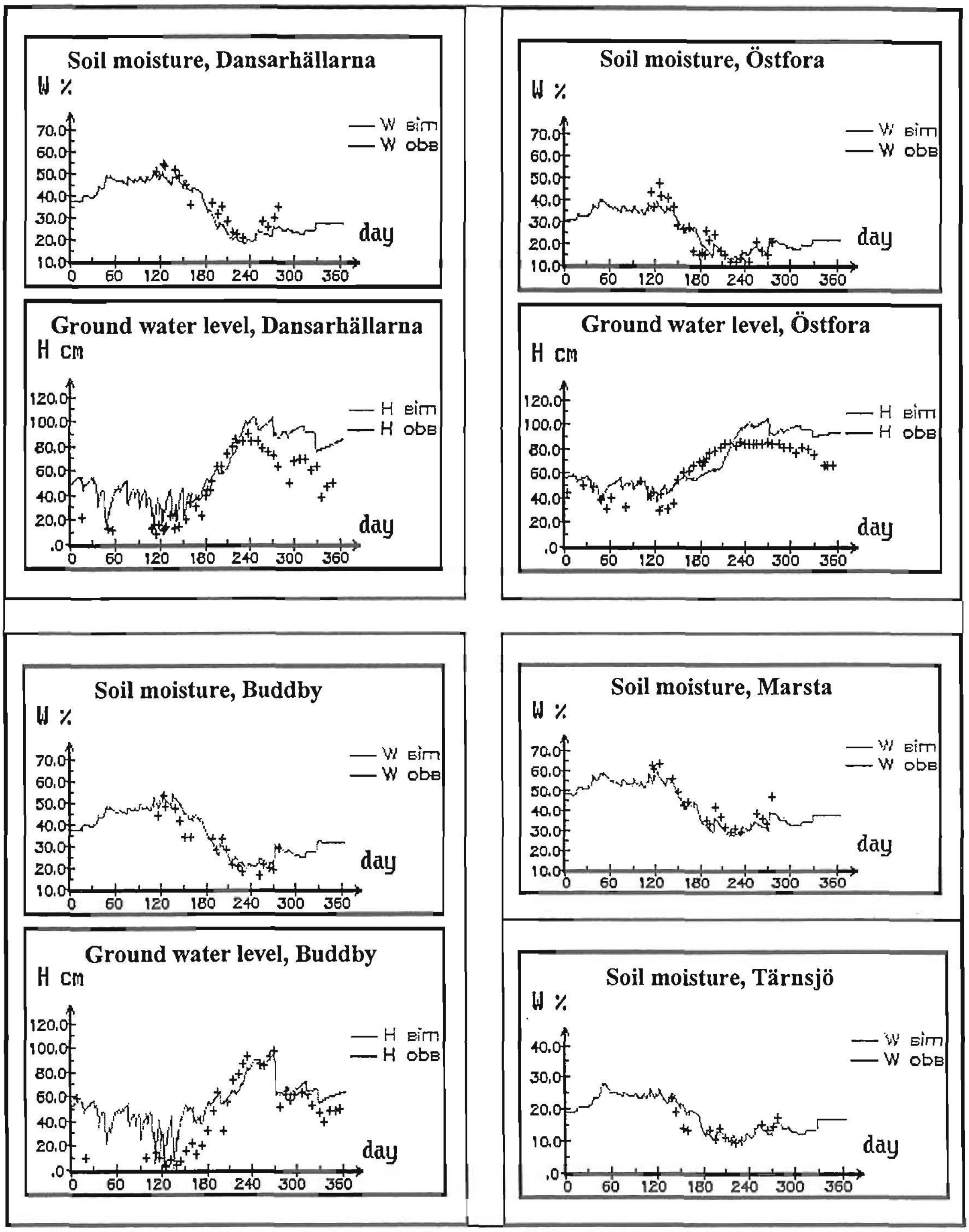

Figure 5. Simulated and observed soil moisture and ground water levels for the five experimental basins.

A more problematic question is the comparison of synoptic runoff observations with those simulated. This focuses attention on the model's ability to reproduce the spatial variation in runoff. The total variability across space as assessed by the 12 synoptic points has a similar pattern for observed and simulated values but the individual deviations between them are difficult to explain at present. It has therefore not been possible to really validate the process description and parameterisation of drainage from individual grid cells. The different simulated water balance components for grid cells show relatively high spatial variability and it has not been possible to confirm this variability from independent observations. This problem needs to be studied further.

Comparison of measured and simulated discharges

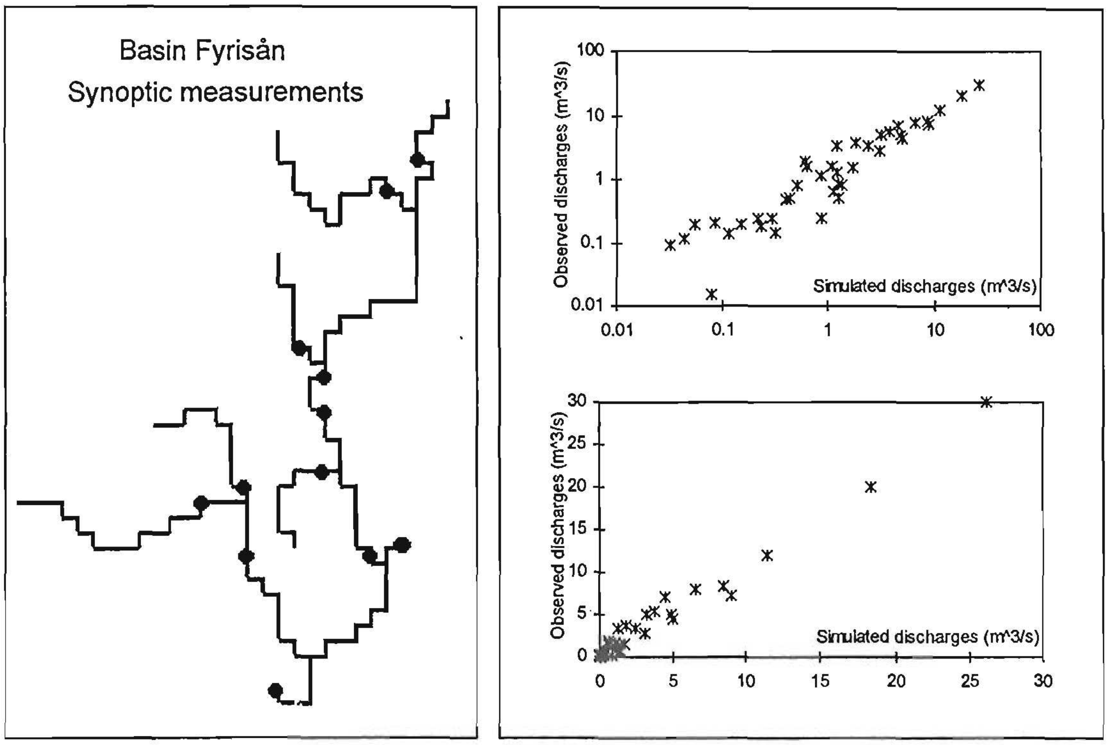

Figure 6. Comparison of measured and simulated discharges

When simulated water balance elements were integrated to the whole NOPEX area, independent estimates from vertical flux measurements of regional evapotranspiration have been used for validation. The noted discrepancies are within the uncertainties of the estimated values. A further step here would be to develop a data assimilation scheme for the regional model taking advantage of all separate data sources, not only those traditionally used in modelling efforts by hydrologists.

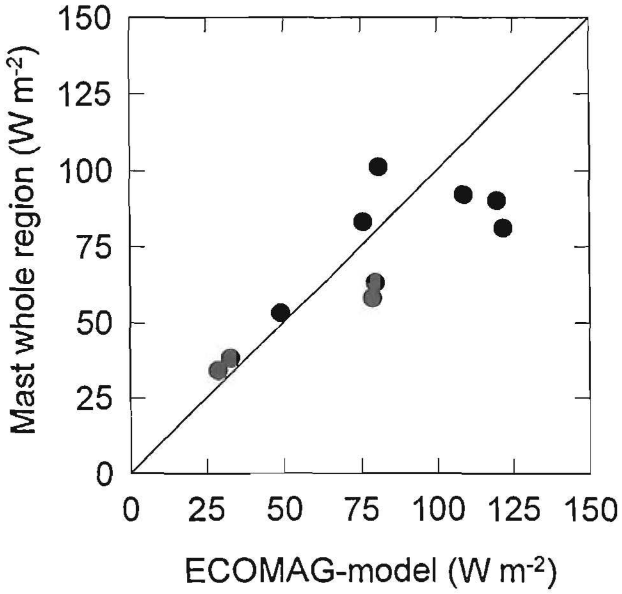

***Figure** 7. Regional latent heat flux estimated by mast measurements using whole region land use data plotted against the estimate made by the ECOMAG-model.*

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More information can also be found on the following site:
http://www.uio.no/~nilsroar/nygenmo

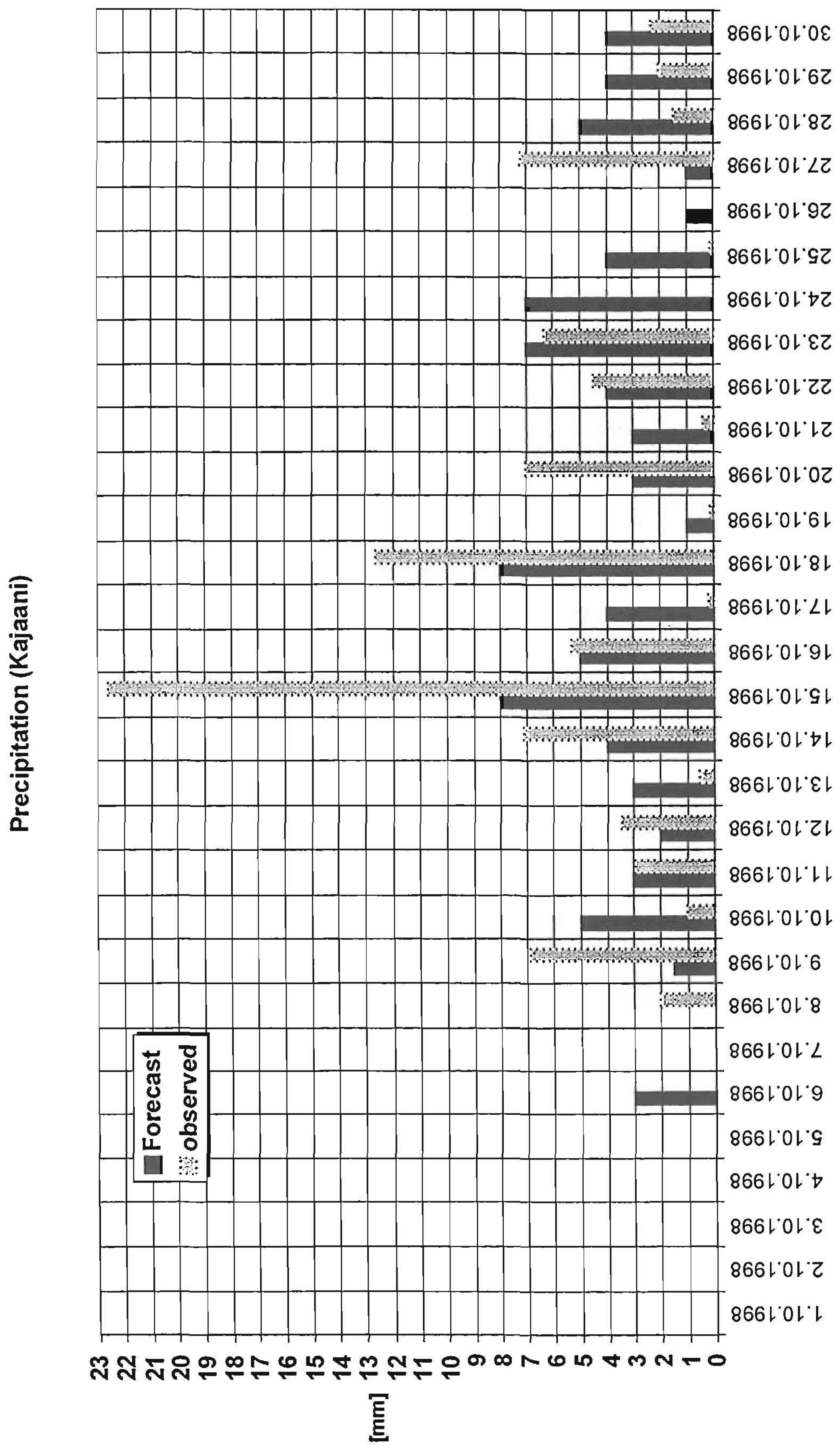


Figure 1. Observed and forecasted rainfall during October-November, 1988.

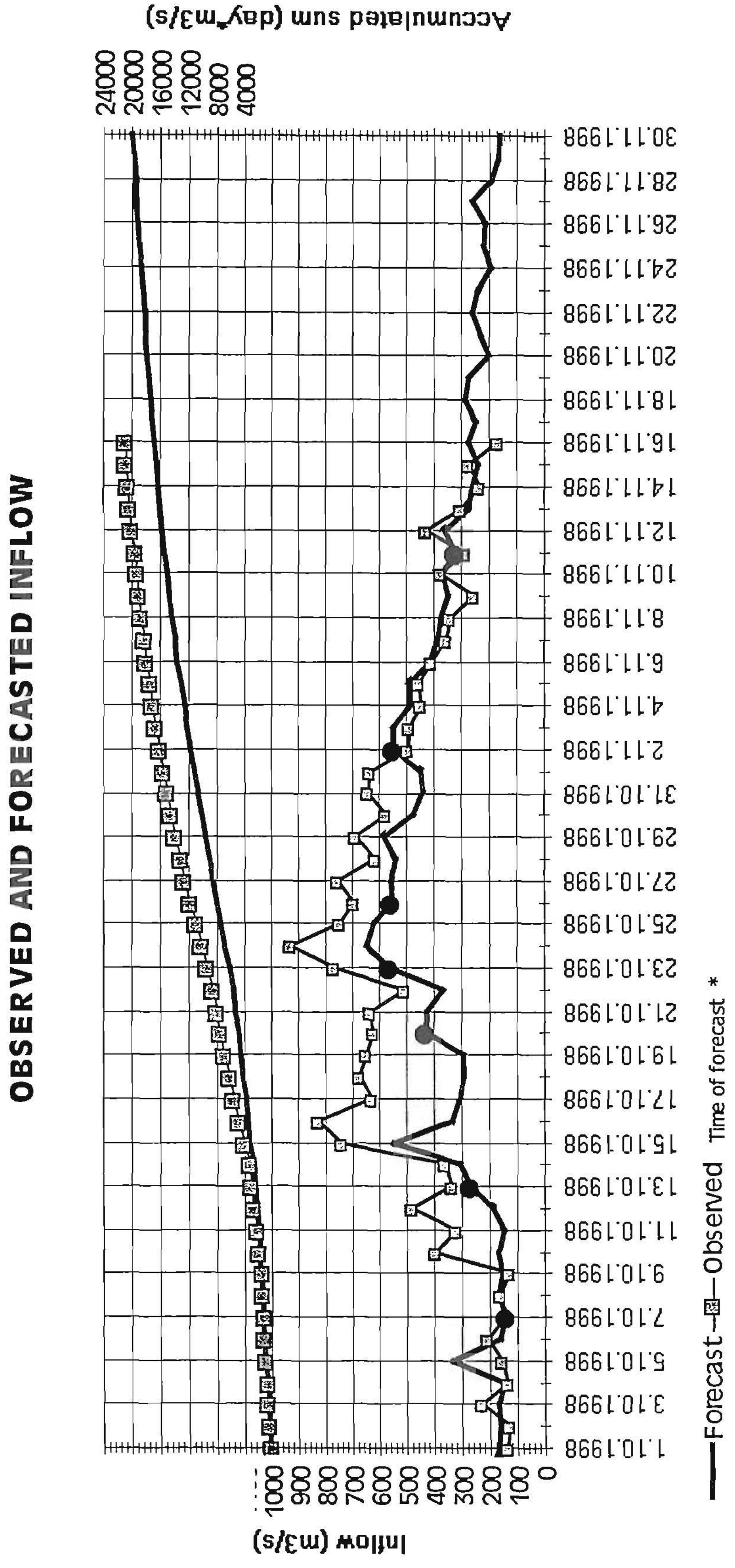


Figure 2. Observed and predicted (unadjusted) total inflow to reservoirs during October -November 1998.

8. THE RIVER KEMIJOKI AND EXPERIENCES IN FLOOD FORECASTS USING HBV-MODEL

Juho Päiväniemi
Kemijoki Oy

The River and Regulations

The catchment area (basin) of river Kemijoki is about 50000 km2. The average runoff to the sea is 550 m3/s and maximum runoff (after regulations) has been 4400 m3/s. There are few natural lakes along the Kemijoki.Two reservoirs , Lokka and Porttipahta, are located quite high up in the north. They are carryover reservoirs, and catch all incoming water during the spring flood. Kemijoki Oy regulates Lake Kemijärvi, too. Lake Kemijärvi is filled during every spring flood and can store then only a little part of inflow. So we have to run much water onwards from the lake, and much of it is spilled. River Ounasjoki joins the main stream at Rovaniemi. It is protected by a special law, and is almost in its natural state. Kemijoki Oy has built 15 power stations along the main river and river Kitinen. The regulations and power stations are operated from Kemijoki Oy's operating center at Rovaniemi. We have water level and discharge measurements on all our lakes, plants and all remarkable rivers. Then we have our own weather stations that measure temperature, rain and wind. The temperature stays below zero about six months and water equivalent of snow is between 120-260 mm in the start of spring flood.

Forecasting

Our main interest has been in spring flood forecasting. Snow melting with possible heavy rainfall can make big damage mainly at Rovaniemi area. When damages are expected, the main way to prevent them is to cut the peak at Rovaniemi by filling the Lake Kemijärvi at the right time. It may be sometimes needed to overtop the lake by a special permission. This can be very risky and good timing and forecasts are essential. The moment of the peak and duration of high flood must be known some days before to take the right actions in right time. Otherwise the damages can even increase and the Kemijärvi dam may be crossed. During the spring flood we use of course all the information we can get beside the forecast. We for instance make snow flights with a little plane to see what is going on. We are especially interested in snow cover and water in temporary storages like swamps and river headwaters. We work in close co-operation with local authorities and have regular meetings during a flood to discuss the forecasts and necessary actions. Spring floods with very little water are important as well. If we over-estimate the size and/or the duration of the flood, we may cause energy losses by spilling too much. Nowadays we are more and more interested in summer time forecasts, too. We can prevent damages, offences against licences as well as energy losses with good forecasts.

In our opinion at Kemijoki, the model has been quite successful in its most important task, forecasting the time and the size of the peak some five days before. We have been using the model for more than ten years. There has been a lively co-operation between developers, users and authorities. This is a newer-ending process towards more reliable, up-to-date and flexible forecasting practice.

9. USE OF HBV-MODEL IN REGIONAL ENVIRONMENT CENTRE OF NORTHERN CARELIA (RECNC)

Jukka Höytämö
Regional Environment Center of Northern Carelia

HBV-model is used in two main purposes in RECNC, namely flood control and information. RECNC is the user of the results calculated by Finnish Environment Institute (FEI). In practice, HBV-model is used by following the WWW-page of FEI. In a few cases also the map-based user interface can be used.

Flood Control

One of the tasks of RECNC is to prevent the potential damages related to exceptional floods in Northern Carelia. In the main, it means the controlling of the water level of the Lake Pielinen.

The permit of the Water Court concerning the discharges of Lake Pielinen has been given to waterpower company in 1978. It determines the discharge according to original rating curve of Lake Pielinen. In case of an exceptional flood RECNC the Water Court asks the permit to carry out the extra discharges.

In order to get the permit there have to be calculations and criteria. HBV model is very useful at this stage. The results of HBV calculations comprise three alternatives: 10%, mean and 90% (Figure 1). According to them it is possible to estimate the amount of the potential damage in different cases.

When carrying out the exceptional permit, HBV-model helps in deciding the amount of the discharge. RECNC gives the advice/order daily to the waterpower station according to the last forecasts made by HBV model.

Information

People are very interested in the news concerning the environment. Newspapers and the radio are very eager to get information. Normally there are numerous contacts in the week between RECNC and the media/citizens. When there's something more extraordinary, the contacts are almost constant.

It is very important to have up-to-date information and also estimates for coming days. The modern HBV system has improved remarkably the possibilities to serve the audience.

The media has also learnt to use the WWW-pages of FEI. In order to avoid the misinterprets, it would be advisable to improve the printed data of the model.

Experiences of the HBV Model

+

- Very handy
- Immediately available
- Gives the sufficient data for flood control and information(alternatives)

-

- The appearance of the print
- The data shown in the print; (Calibrated precipitation data)
- Changing results in short time (F.Ex. 10-20 cm in Pielinen without any significant change in input data)
- 1/3 Of The drainage area is in Russia; no observations, a possibility for errors ?

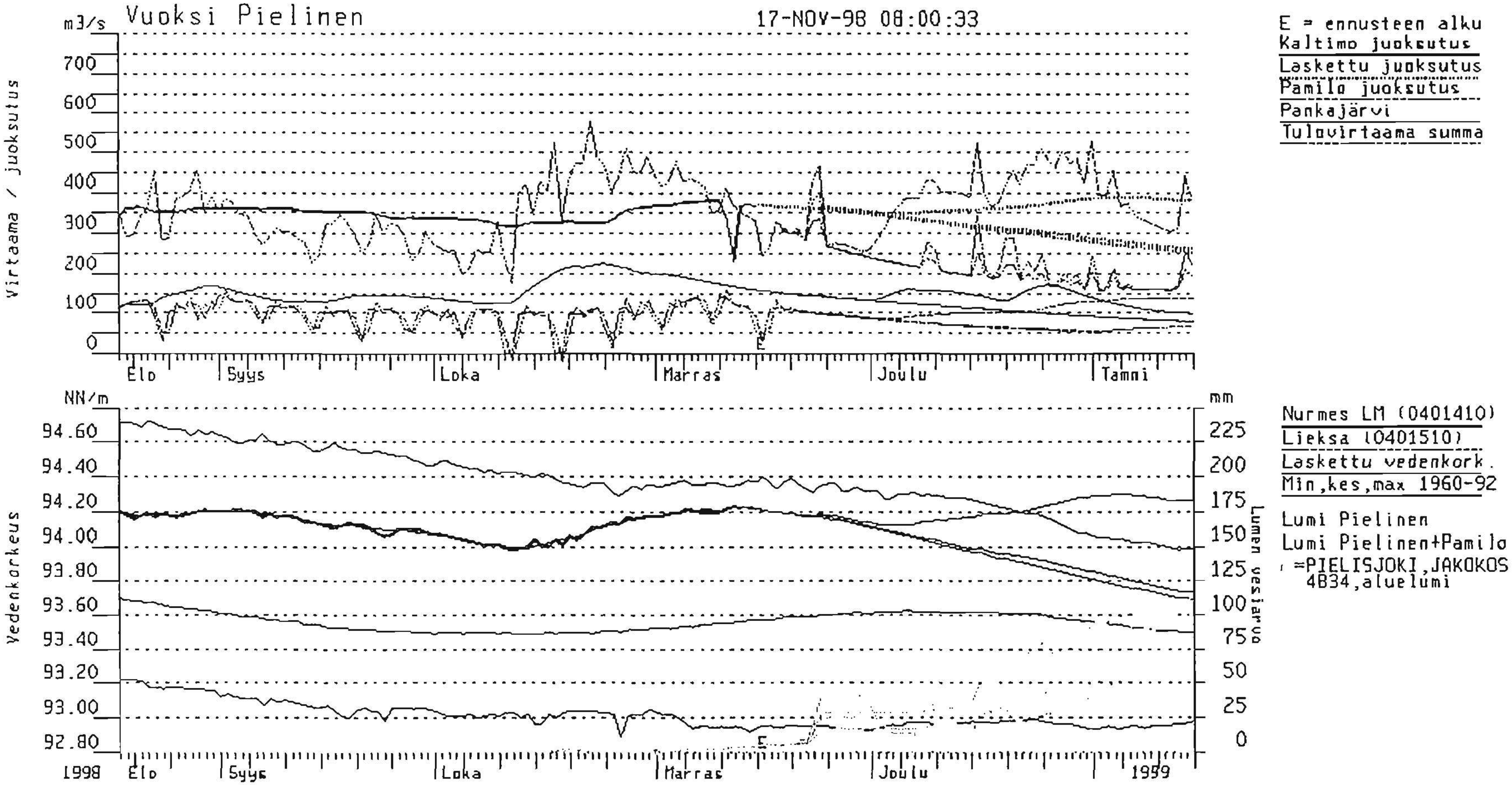


Figure 1. The results of HBV forecast on 17. November 1998

10 vrk:n sääennuste on ECMWF:n ennuste. 10 vrk:n sadesumma asemille on 18.8 mm.

	pvm	16.11.	17.11.	18.11.	19.11.	20.11.	21.11.	22.11.	23.11.	24.11.	25.11.		16.11.	17.11.	18.11.	19.11.	20.11.	21.11.	22.11.	23.11.	24.11.	25.11.
Kuopio	Lämpö	-6.6	-6.8	-7.6	-7.9	-7.9	-7.4	-7.4	-7.3	-6.3	-3.6	Sade	0.0	0.0	0.0	1.0	0.0	2.0	0.0	9.0	9.0	0.0
Joensuu	Lämpö	-14.4	-15.0	-15.3	-16.3	-15.9	-15.6	-15.5	-12.3	-9.9	-6.1	Sade	0.0	0.0	0.0	1.0	0.0	1.0	0.0	8.0	10.0	0.0
Ilomantsi	Lämpö	-14.8	-14.5	-14.9	-16.5	-16.3	-16.3	-16.1	-13.0	-10.1	-5.9	Sade	0.0	0.0	0.0	0.0	0.0	1.0	0.0	7.0	11.0	0.0

Ennustejakson sää: 981116-981125 sadesumma Pielinen14 on 21 mm
981126-981226 ka. sade,Pielinen14 on 45 mm
981126-990125 ka. sade,Pielinen14 on 88 mm
981126-990224 ka. sade,Pielinen14 on 122 mm
981126-990326 ka. sade,Pielinen14 on 151 mm
981126-990425 ka. sade,Pielinen14 on 188 mm
981126-990525 ka. sade,Pielinen14 on 235 mm

Ennuste 2981116-981125 sadesumma Pielinen14 on 22 mm
981126-981226 90% sade,Pielinen14 on 72 mm
981126-990125 90% sade,Pielinen14 on 124 mm
981126-990224 90% sade,Pielinen14 on 164 mm
981126-990326 90% sade,Pielinen14 on 200 mm
981126-990425 90% sade,Pielinen14 on 244 mm
981126-990525 90% sade,Pielinen14 on 291 mm

Ennuste 2981116-981125 sadesumma Pielinen14 on 10 mm
981126-981226 10% sade,Pielinen14 on 24 mm
981126-990125 10% sade,Pielinen14 on 52 mm
981126-990224 10% sade,Pielinen14 on 80 mm
981126-990326 10% sade,Pielinen14 on 92 mm
981126-990425 10% sade,Pielinen14 on 132 mm
981126-990525 10% sade,Pielinen14 on 157 mm

10. VESISTÖJEN SÄÄNNÖSTELY POHJOIS-SAVOSSA

Jukka Hassinen
Pohjois-Savon ympäristökeskus

Yleistä

Pohjois-Savon ympäristökeskus on säännöstelyluvan haltijana Vuoksen vesistöalueella Kiuruveden, Onki- ja Poroveden sekä Kallaveden ja Unnukan säännöstelyissä. Kymijoen vesistöalueella. säännöstelyvastuu on Hirvi-, Ahvenisen- ja Kalliojärven säännöstelyissä.

Säännöstelyhankkeet on pantu vireille Onki- ja Poroveden säännöstelyssä jo 1950-luvun alkupuolella. Vuonna 1972 aloitettiin Unnukan ja Kallaveden säännöstely. Säännöstelyperuste on Unnukan ja Kallaveden säännöstelyssä pääosin hyötyliikenteen turvaaminen. Tämä ei ole kuitenkaan ristiriidassa vesien muulle virkistyskäytölle. Iisalmen reitin säännöstelytavoite on lähinnä alentaa tulvakorkeuksia, josta muutoin aiheutuisi haittaa maataloudelle. Onki- ja Poroveden säännöstelysuunnitelman tarkistamisen yhteydessä oma painoarvo on ollut myös kalaston elinolosuhteiden parantamisella. Tähän on pystytty vaikuttamaan kevätaikaisten vedenkorkeuksien tasolla ja kestolla.

Kiurujärven säännöstely hoidetaan Runnilla sijaitsevalla Saarikosken padolla. Poroveden säännöstely hoidetaan Nerohvirran padolla ja Onkiveden säännöstely Viannonkosken padolla. Tarvittaessa tulvajuoksutuksiin voidaan käyttää myös rinnakkaisia Nerkoon ja Ahkiolahden sulkukanavia. Iisalmen reitin valuma-alueen koko on (F) 5 600 km^2 ja järvisyys (L) 7,7 % (Viannonkoski), virtaama $HQ_{1/20}$= 250 m^3/s.

Kallaveden säännöstely hoidetaan Leppävirralla sijaitsevilla Konnuksen kanavalla ja Naapuskosken padolla. Unnukan osalta säännöstelyn ja säännöstelyrakenteiden hoidosta vastaa Enso Oy Pohjois-Savon ympäristökeskuksen ohjeiden mukaisesti. Kallaveden valuma-alueen koko on noin 16 000 km^2 ja järvisyys (L) 15,3 % (Konnus + Karvio), virtaama $HQ_{1/20}$= 340 m^3/s. Kymijoen vesistöalueen säännöstely hoidetaan Haringan ja Savikosken padoilla.

Säännöstelyrajat ovat Kiurujärvessä 1,7 m, Onki- ja Porovedessä noin 1,0 m. Säännöstelylle on kesäajaksi asetettu tavoitekorkeudet ja niihin sallitaan +/- 0,10 m:n vaihtelu. Kallaveden alueella vaihteluväli purjehdusaikana on 0,75 m. Vastaava-arvo on Unnukassa 0,35 m.

Voimayhtiöiden ym. tahojen säännöstelyhankkeet

Vuoksen vesistöön kuuluvan Nilsiän reitin (Vuotjärvi, Syväri, Korpinen, Sälevä, Kiltuan- ja Haajaisen järvi ja Laakajärvi) ja myös pienempien Sorsaveden ja Salahminjärven säännöstelyistä vastaa Savon Voima Oy. Säännöstelyn tavoite on pääasiasiassa (tehokas) sähköntuotanto. Nilsiän reitin valuma-alueen koko on noin 4 100 km^2 ja L = 10,4 %, virtaama $HQ_{1/20}$= 250 m^3/s.

Kymijoen vesistöön kuuluvat Kiesimä-, Sonkari- ja Vesantojärven sännöstelystä vastaa Järvi-Suomen merenkulkupiiri. Säännöstely toteutetaan Kerkonkosken padolla, tarvittaessa sulkukanavaa apuna käyttäen.

Keskeisimmät säännöstelyhankkeet

Unnukan säännöstely

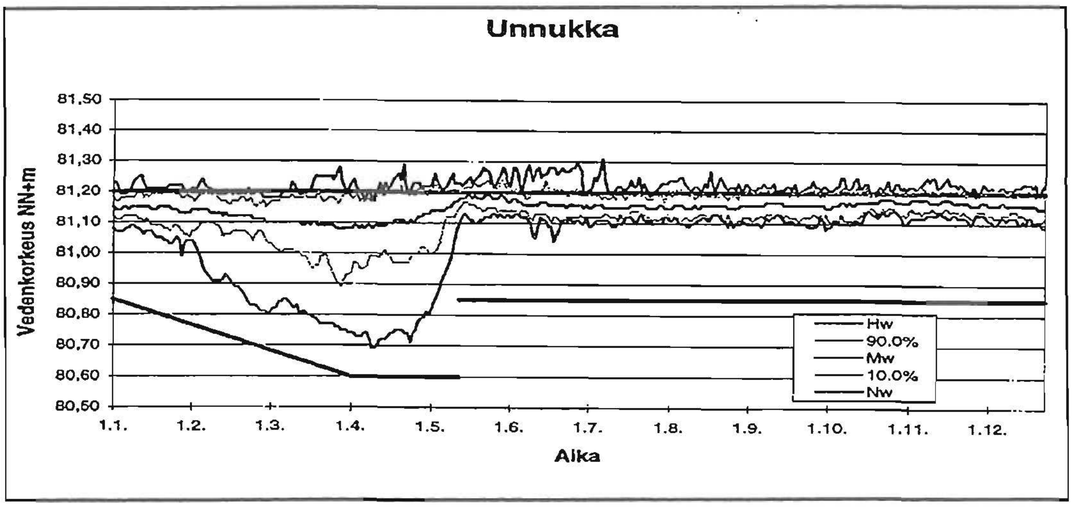
Säännöstelyä hoidetaan Itä-Suomen vesioikeuden päätöksen mukaisesti. Unnukan säännöstely tapahtuu Varkaudessa sijaitsevalla Enso Oy:n omistamalla Huruskosken voimalaitoksella sekä Ämmäkosken padoilla. Tulva-aikana, voidaan juoksutuksiin käyttää myös Taipaleen vesiliikennekanavaa. Säännöstely on hoidettava keskeisimpien lupaehtojen mukaan seuraavasti (Kuva 1):

A. Vedenkorkeus ei saa ylittää korkeutta NN + 81,20 m.

B. Laivaliikennekaudella 1.5.-10.12. välisenä aikana vedenkorkeus ei saa alittaa korkeutta NN + 81,10 m.

C. Syksyllä laivaliikennekauden jälkeen 31.12. saakka ei vedenkorkeus saa alittaa korkeutta NN + 80,85 m. Talvella ei vedenkorkeus saa alittaa 1.1.-31.3. taitepisteiden välistä janaa.

D. Säännöstely on lisäksi hoidettava siten, että Unnukasta alas voidaan juoksuttaa jatkuvasti vähintään 17,5 m^3/s vuorokausikeskiarvona.



Kuva 1. Unnukan säännöstelyn ohjepiirros sekä vedenkorkeuskäyriä säännöstelyjaksolla 1973-1994.

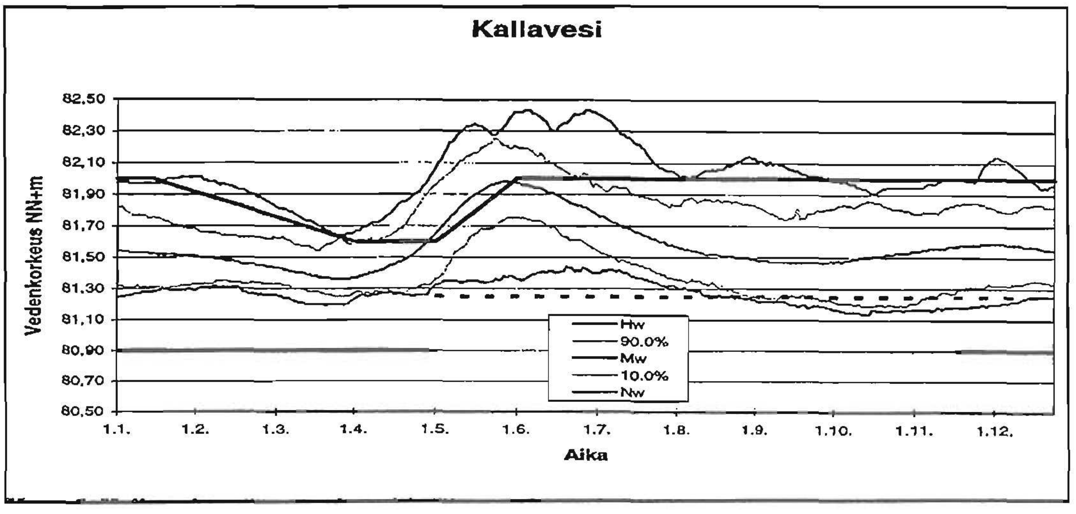
Kallaveden säännöstely

Kallaveden säännöstely hoidetaan Naapuskosken (Leppävirta) säännöstelypadolla käyttäen juoksutuksiin tarvittaessa myös Konnuksen vesiliikennekanavaa. Säännöstely on hoidettava lupaehtojen mukaan seuraavasti (Kuva 2):

A. Vedenkorkeus ei saa alittaa korkeutta NN + 80,90 m. Laivaliikennekaudella vedenkorkeus ei saa alittaa korkeutta NN + 81,25 m.

B. Korkeuden NN + 82,00 m (1.1.-10.6. välisenä aikana) yläpuolelle nousevien tulvakorkeuksien alentamiseksi suoritetaan Konnuksen kanavan ja Naapuskosken padon kautta juoksutuksia. Tarvittavat tulvajuoksutukset määräytyvät seuraavien parametrien perusteella:

- vuorokautisten tulovirtaamien summan (1.1.-20.1.) ja Kallaveden vesistöalueella 15.1. mitatun lumen vesiarvon perusteella.
- Kallaveden vesistöalueen 1.10.-28.2. välisen ajanjakson sadesumman S ja helmikuun sadannan perusteella.
- 11.4.-10.6. välisenä aikana mitatun lumen vesiarvon (31.3.) ja maaliskuun sadesumman perusteella.



Kuva 2. Kallaveden säännöstelyn ohjepiirros sekä vedenkorkeuskäyriä säännöstelyjaksolla 1973-1994.

Säännöstelyn vaikutukset

Kalasto ja eliöstö

Onki- ja Poroveden säännöstelyn tarkistamistyön yhteydessä tehtiin Kuopion yliopiston toimesta selvityksiä säännöstelyn vaikutuksesta kalastoon. Säännöstelyllä ei todettu voivan vaikuttaa suoranaisesti veden laatuun, epäsuorasti kylläkin. Säännöstelyn amplitudin pienuudesta johtuen sillä ei ole suoranaista vaikutusta pohjaeläinten ja kasvien määrään ja lajisuhteisiin.

Talven alivedenkorkeus ja vedenpinnantason pitäminen riittävän pitkään suotuisalla tasolla, turvaisi parhaiten mateen kudun onnistuminen. Kevättulvan vastaavasti tulisi olla niin voimakas, että se nostaisi kuolleen vesikasviaineksen rannalle ja poistaisi vesistöstä näin suuren määrän ravinteita. Kalaston hoitoa ajatellen tulvan tulisi olla ajallisesti riittävän pitkä, jotta hauen kutu onnistuisi ja poikaset ehtisivät uida rantavyöhykkeestä pois.

Vesiliikenne ja vesien virkistyskäyttö

Veneilyn ja vesien virkistyskäytön kannalta alhaiset vedenkorkeudet ovat ongelmallisia lähinnä Syvärin -Vuotjärven sekä Haajaisten -Kiltuan järvien vesistöalueella. Säännöstelyn vaihteluväli on purjehdusaikana 1,5-2,0 m. Tämä on aiheuttanut ongelmia vesilläliikkujille (karit) sekä rantarakenteille (laiturit). Vesilläliikumista on pyritty turvaamaan merkitsemällä venereittejä. Muualla ei vastaavia ongelmia ole esiintynyt.

Hyötyliikenteen osalta Kallaveden laskeminen alarajan pintaan purjehdusaikana aiheuttaa lastien pienentämistarvetta. Mikäli vedenpinta laskee purjehduskautena alarajan alle, aiheutuu siitä lisäkustannuksia kuljetusyhtiöille.

Rantaeroosio

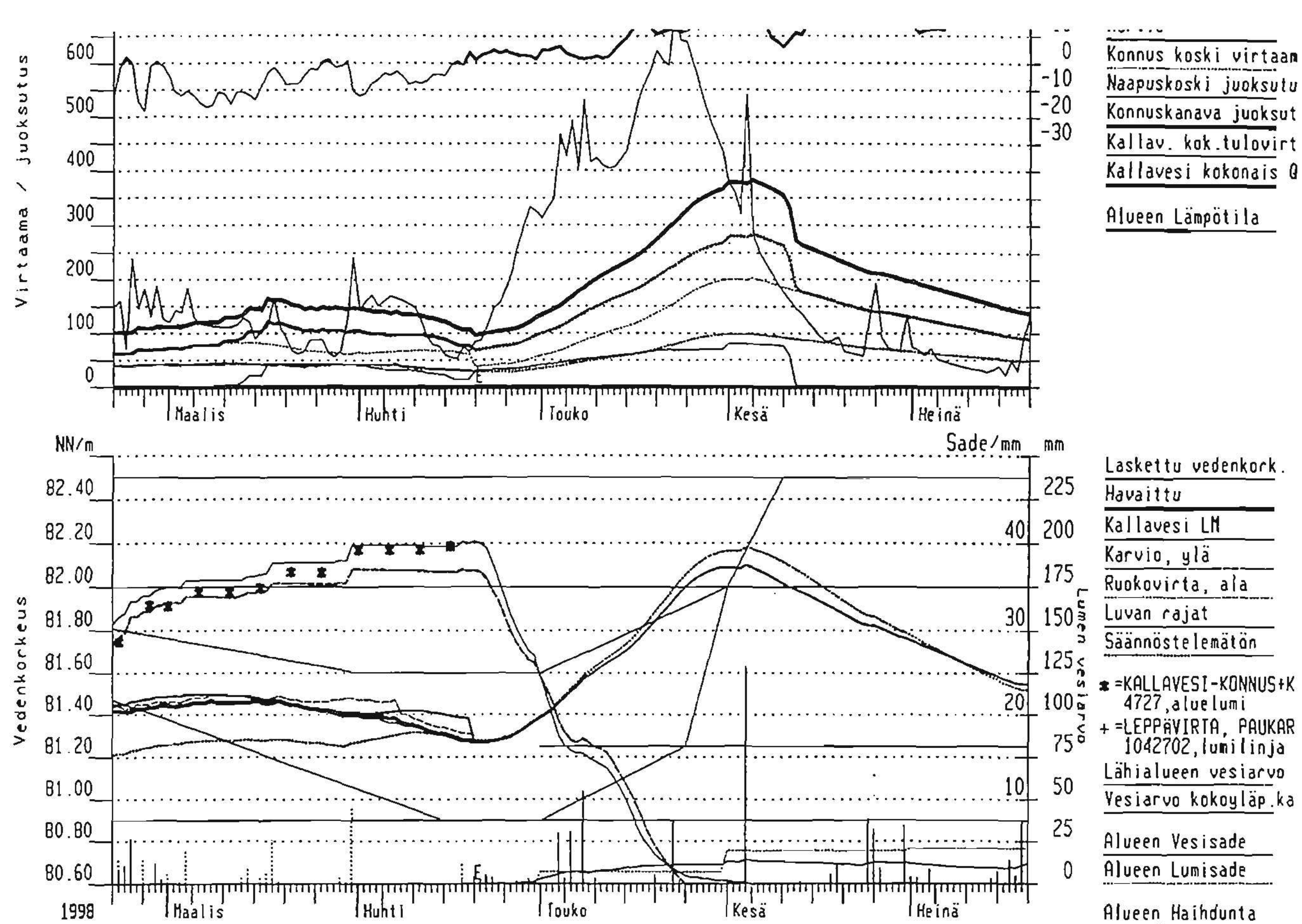
Voimakkaasti säännöstellyissä vesistöissä, lähinnä Haajaisen, Kiltua ja Laakajärven rantavyöhykkeissä on havaittavissa kasvavaa eroosiota. Mikä on tuulen ja mikä on säännöstelyn vaikutus prosessissa ei vielä ole pystytty osoittamaan. Onki- ja Poroveden säännöstelyssä kesäaikana nopeat vedenpinnan vaihtelut on koettu ongelmana virksityskäytön kannalta. Varastotilavuuden pienuudesta johtuen vedenpinnan muutos on varsin nopea. Vaihtelurajaa suurentamalla voitaneen tätäkin ongelmaa lievittää. Nykyinen vaihteluraja on 0,45 m.

Ennusteiden ja säännöstelymallien hyödyntäminen

Säännöstelymalleista ja ennusteista saatava hyöty on merkittävä. Ennen säännöstely oli enemmän "tunne" -tasolla. Säännöstely saattoi vuosia onnistua hyvin. Olivatko olosuhteet stabiilimmat verrattuna nykytilanteeseen, siihen ei liene tällä hetkellä olemassa varmaa vastausta (kun tarkastelun pohjana on "riittävän" pitkä aikasarja). Ilmastossa mahdollisesti tapahtuneet muutokset ovat tehneet sen, että ns. poikkeusvuodet ovat yleistyneet. Sateet ovat rankkoja ja näin ollen säännöstelyn eri osa-alueilla tulee reagoida riittävän nopeasti. Lupaehtojen ollessa vastaavasti varsin tiukat (+/- 0,10 m), asettaa se erityisiä vaatimuksia säännöstelylle. Mallien ja ennusteiden avulla voidaan varautua niin hyvin kuin se voi nykyisellä tekniikalla ja eri tahojen intressit ottaen huomioon olla yleensä mahdollista. Mallien ja ennusteiden avulla pienennetään epäonnistumisen riskiä säännöstelytehtävien hoidossa.

Esimerkiksi 22.4.1998 on ennustejaksoksi valittu 10 vrk ja sadesummaksi on arvioitu 38 mm. Virtaamaa tulee ennusteen mukaan lisätä huomattavasti, jotta tavoitekäyrään päästään (Kuva 3). Ilman ennustetta ja tarvittavia mallilaskelmia tilanne ei olisi kehittynyt niin hyvin. Vedenpinta noudatteli likimäärin tavoitekäyrää.

Uuden kaukomittaustekniikan avulla pystytään havainnoimaan reaaliajassa vesipinnoissa tapatahtuneet muutokset ja tarvittavat laskennat saadaan aikaistettua päiviä jopa viikkoja aiemmin. Tällöin saadaan lisäaikaa poikkeustilanteiden ennustemallien ajamiselle ja tilanteeseen sopivan säännöstelyn toteuttamiselle.



10 vrk:n sääennuste on ECMWF:n ennuste. 10 vrk:n sadesumma asemille on 3.8 mm.

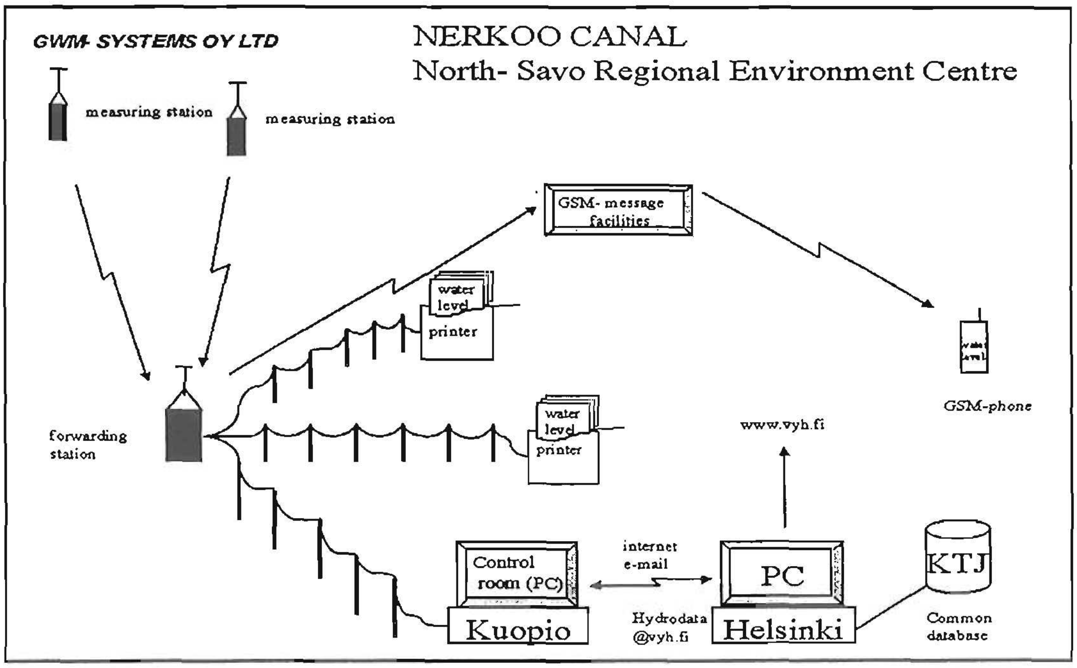
	pvm	21 4.	22. 4.	23. 4.	24. 4.	25. 4.	26 4.	27 4	28 4.	29. 4	30. 4.		21. 4.	22. 4.	23. 4.	24. 4.	25 4.	26. 4.	27. 4.	28. 4.	29 4.	30. 4.
Kuopio	Lämpö	2.6	3.4	4.6	3.3	4.1	3.5	2.8	2.6	2.5	1.3	Sade	0.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0
Joensuu	Lämpö	2.1	3 3	4.9	4.0	5.0	4 8	4 1	4.8	3.8	2.5	Sade	0.0	1.0	0.0	0.0	0.0	1 0	0.0	0.0	1.0	0.0
Kajaani	Lämpö	4.0	4 3	5 1	4.1	4.9	3 6	2.9	2.0	1.9	1.0	Sade	1.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0

Ennustejakson sää: 980421-980430 sadesumma Kallavesi on 4 mm 980501-980531 ka. sade,Kallavesi on 37 mm 980501-980630 ka. sade,Kallavesi on 100 mm 980501-980730 ka. sade,Kallavesi on 166 mm
980501-980829 ka. sade,Kallavesi on 240 mm 980501-980928 ka. sade,Kallavesi on 307 mm 980501-981028 ka. sade,Kallavesi on 363 mm 980501-981028 ka. lämpötila
Sadejakauma= v.84 lämpöjakauma= v.84

Kuva 3. Esimerkki ennusteiden hyväksikäytöstä, tilanne 22.4.1998.

Kaukomittausjärjestelmä

GWMS 2001 Kaukomittausjärjestelmä järjestelmä koostuu kolmesta eri komponentista; Mittausasemasta, välitysasemasta sekä valvomosta. Mittausaseman tehtävänä on mitata ennaltä määrätyin välein pinnankorkeustietoa ja tallettaa sen mittausaseman loggeriin. Mittausasema lähettää mittaustulokset välitysasemalle myöskin ennalta määrätyin välein. (Kuva 4)



Kuva 4. Kaukomittausjärjestelmän toimintaperiaate

Välitysaseman tehtävä on välittää mittausasemalta tulevat tulokset puhelinverkkoon ja jakaa mittaustulostieto valvomoon, padonhoitajille sekä lähettää GSM- tekstiviestinä mittaustulos käsipuhelimeen. Valvomo sijaitsee Kuopiossa, padonhoitajille tieto tulee kirjoittimille jotka sijaistevat heidän kotonaan.

Valvomon tehtavä on ottaa tulokset vastaan ja tallettaa tulokset haluttuihin tiedostoihin. Tietojen eteenpäin välitys "valvomokoneelta" tapahtuu eräajona. Eräajossa tiedot lähetetään sähköpostilla internetin kautta osoitteeseen HYDRODATA@vyh.fi. Hydrodata jakaa sähköpostitse tulleet mittaustiedot eteenpäin mm. käyttöjärjestelmään, jossa pinnankorkeustiedot ovat kaikkien ympäristökeskusten käytettävissä. Lisäksi mittaustiedot voidaan asettaa www-sivuille yleiseen käyttöön.

Yleistä GWMS 2001 järjestelmästä:

Järjestelmän kentällä sijaitsevat mittausasemat ovat suunniteltu toimimaan ilman kiinteitä ulkopuolisia sähkö-ja tietoliikenneyhteyksiä. Tähän on päästy kehittämällä dataloggeri, jonka oma virrankulutus on mahdollisimman pieni, ja joka kykenee käyttämään erilaisia langattomia tietoliikenneyhteyksiä (radio- ja GSM-modeemit). Järjestelmä kykenee toimimaan pienen akun avulla 3-9 kk, ja aurinkopaneelin avulla ympäri vuoden.

Valvomo ohjelmisto kykenee ottamaan vastaan useiden mittausasemien tiedot, riippumatta millä tavoin tieto siirretään mittausasemalta valvomoon. Välitysaseman avulla mittaustietoja voidaan lähettää useaan eri paikkaan ja esim. GSM-tekstiviestin lähetys päivittäin on mahdollista. Lisäksi mittaustietoja voidaan siirtää mittausasemalta suoraan GSM- verkon kautta valvomoon, käyttämällä GSM-modeemia.

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Nordic Workshop on HBV and Similar Runoff Models
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Abstract

The content of this publication consists of the presentations held in the Nordic workshop on HBV and similar models in Helsinki 19. - 20.11.1998. HBV-model is developed in Sweden (SMHI) in the beginning of the 1970's. First forecast runs for operative purposes were made in the year 1975. HBV-model and HBV-based model versions and applications are in use not only in Nordic countries but totally in 40 different countries. Since 1970's there have been done lot of model related development work especially in 1990's. This workshop was decided to be held for clarifying the development work done in each participating country and to define the potential fields for future cooperation. Total number of participants was 20 and 12 presentations were given. The possibilities for use and different applications are wide: hydrological forecasting, simulation, water balance mapping, design floods, land use impacts, groundwater, soil moisture, water quality and climate change studies. The presentations introduced the development work in participating countries. Also the opinions and suggestions of those persons responsible of the use of models and operative use of water courses (lake regulation and hydro production) was brought out.

Keywords
hydrology, forecasts, modelling, watershed models, precipitation, water equivalent, HBV-model, floods, simulation, operative use of water courses, regulation, hydro power

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Julkaisun sisältö koostuu Helsingissä 19. - 20.11.1998 pidetyn hydrologisia HBV -malleja käsitelleen pohjoismaisen workshopin esitelmistä. HBV-malli on kehitetty Ruotsissa (SMHI) 1970 -luvun alussa ja ensimmäiset vesistöjen operatiivistä käyttöä palvelevat ennusteet tehtiin vuonna 1975. HBV -malli ja siitä kehitetyt erilaiset versiot ovat yleisesti käytössä pohjoismaissa ja muualla maailmassa, yhteensä noin 40 eri maassa. Pohjoismaissa malleihin liittyvää kehitystyötä on tehty runsaasti varsinkin 1990-luvulla. Workshop päätettiin järjestää hydrologisten mallien kehitystilanteen kartoittamiseksi ja yhteistyömahdollisuuksien selvittämiseksi. Osallistujia oli yhteensä 20 ja kokouksen aikana pidettiin 12 esitelmää. HBV-mallien käyttö- ja sovellusmahdollisuudet ovat laajat: hydrologiset ennusteet, simulointi, vesitasekartat, mitoitustulvalaskennat, maankäytön vaikutukset, pohjavesi, maankosteus, veden laatu sekä ilmastonmuutokseen liittyvät selvitykset.Pidetyissä esitelmissä tuotiin esille osallistujamaissa tehtävää kehitystyötä sekä mallien käytöstä ja vesistöjen operatiivisesta (säännöstelyt ja vesivoiman tuotanto) käytöstä vastaavien näkemyksiä ja mielipiteitä.

Asiasanat (avainsanat)

hydrologia, ennusteet, mallintaminen, vesistömallit, sadanta, vesiarvo, HBV-malli, tulvat, simulointi, vesistöjen operatiivinen käyttö, säännöstely, vesivoima

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Telefax (09) 4030 0190
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Referat

Innehållet i denna publikation består av föredrag som presenterades vid den nordiska workshopen om HBV-modeller som hölls i Helsingfors 19. - 20.11.1998. HBV-modellen är utvecklad i Sverige (SMHI) i början av 1970 -talet och de första prognoserna för operativ användning av vattendrag gjordes år 1975. HBV-modellen och de olika versionerna som utvecklats av den är i allmänt bruk i de nordiska länderna och också i andra delar av världen, totalt i 40 länder. I de nordiska länderna har utvecklingsarbete av modellerna gjorts speciellt på 1990 -talet. Beslut om denna workshop gjordes för att kartlägga utvecklingssituationen gällande hydrologiska modeller och möjligheterna för nordiskt samarbete. Mötet samlade 20 deltagare och 12 föredrag presenterades. Användnings- och tillämpningsmöjligheterna av HBV-modeller är mångsidiga: hydrologiska prognoser, simulering, vattenbalanskartor, hydrologisk dimensionering av övesvämningar, effekter av markanvändning, grundvatten, markfuktighet, vattenkvalitet samt utredningar i anslutning till klimatförändringen. I de presenterade föredragen framfördes utvecklingsarbetet i deltagarländerna samt deras synpunkter och åsikter som ansvarar för användningen av modellerna och som utnyttjar resultaten för vattendragens operativa bruk (vattenreglering och vattenkraftsproduktion).

Sakord (nyckelord)
hydrologi, prognoser, modellteknik, hydrologiska modeller, nederbörd, vattenvärde, HBV-modell, översvämningar, simulering, operativ användning av vattendrag, reglering, vattenkraft

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